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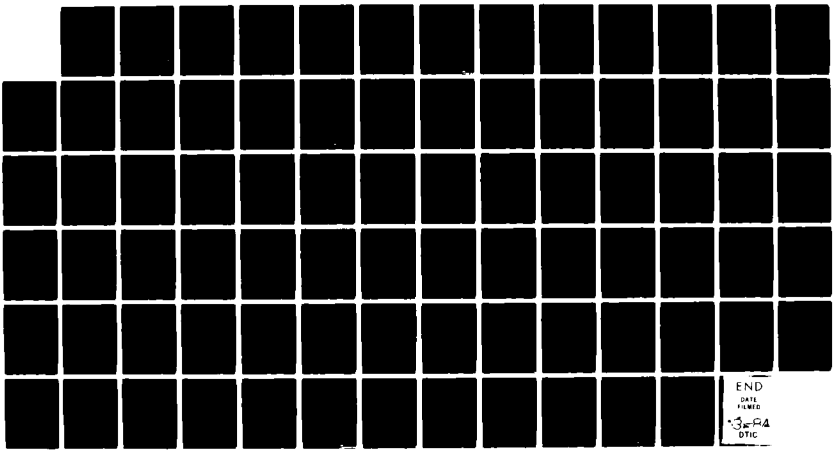

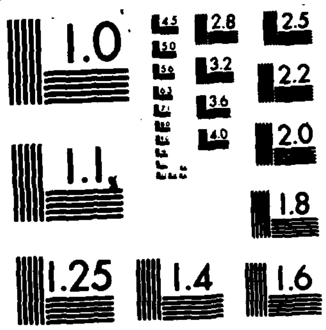


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# Prototypal Application of a Drought Management Optimization Procedure to an Urban Water Supply System

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This report illustrates the validity of a planning method for developing optimal shortage mitigation plans for urban water supplies.

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# PROTOTYPAL APPLICATION OF A DROUGHT MANAGEMENT OPTIMIZATION PROCEDURE TO AN URBAN WATER SUPPLY SYSTEM

Presneted to:

U.S. Army Engineer Institute for Water Resources
Casey Building
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# I. INTRODUCTION

## Objectives

The overall objective of this research project is to illustrate the validity of a planning method for developing optimal shortage mitigation plans for urban water supplies. This method, referred to as drought optimization procedures (or the DROPS model), has been formulated in the first part of the study described in the report - The Evaluation of Drought Management Measures for Municipal and Industrial Water Supplies. The method comprises several concepts, procedures, and measurement techniques which are designed to provide all the information which is needed in order to determine optimal strategies for mitigating drought-related water shortages. Accordingly, the specific objectives of the study reported herein are related to major elements of the DROPS model which are performed in order to fully demonstrate its application. These include:

(1) development of monthly disaggregated water demand model for the service area based on the time series data;

(2) preparation of long-term water demand forecasts;

(3) assessment of water supply availability during shortage events for both existing water supply sources and with new supply additions;

(4) determination of possible supply deficits in future years;

(5) identification and evaluation of potential demand and loss reduction measures;

(6) identification and evaluation of potential emergency supplies;

(7) determination of optimal shortage mitigation plans; and,

(8) assessment of capacity expansion plans in terms of the reduced costs of shortage mitigation.

The completion of these objectives is described in the remainder of this report including a detailed documentation of data gathering and analysis. Springfield, Illinois was selected to illustrate this application due to the availability of data on water supply and use and willingness of the local utility to participate.

## General Site Description

Springfield, the capital city of Illinois and the county seat of Sangamon County is located at the intersection of Interstate Highways 55 and 72, 190 miles south of Chicago. Its elevation is 600 feet above sea level. The general topography of the area is undulating or slightly rolling. Springfield occupies the upland of the Sangamon River Valley located 50 to 100 feet below.

The first settlement in Springfield was made in 1818. In 1832 it was incorporated as a town with a population of slightly over 1,000. The economic importance and future growth of this city were assured when it was made the state capital in 1837. By 1884 Springfield had a population of 30,000 thus becoming the fourth largest city in Illinois. At the turn of the century, the city, after sharing in the country's industrial revolution, was consolidating her utilities and establishing institutions to govern schools, parks, and industries. The city's progress has been steady and consistent in its trend with economy mostly concerned with agriculture, coal mining and the government.

A municipally-owned water supply system managed by the Springfield City Water, Light, and Power (CWLP) supplies water to the urban area and eight surrounding communities. A map of the Springfield area showing the territory served by the CWLP, and the water sources are shown in Figure 1.

Service Area Characteristics

Climate. The climate of the service area is continental with warm summers and fairly cold winters. Monthly average temperatures range from the upper twenties for January to the upper seventies for July, with average summer temperature of 79°F and average winter temperature of 29°F.

There are no distinct wet and dry seasons. Mean monthly precipitation ranges from a little over 4 inches in May and June to about 2 inches in January. The average annual rainfall of 35 inches varies within the absolute range extending from less than 23 inches in 1940 to 58 inches in 1982. The average annual snowfall is about 22 inches, but snow tends to disappear within a few days after it falls.

The state of Illinois experienced 19 droughts of various durations and intensities during this century. The Springfield water supply system was severely affected only by the drought that occurred in the mid-1950's.

Population served. Service area boundaries do not coincide with political subdivisions, however, the area was approximated by using 31 census tracts which constitute the urbanized area including four separate communities in addition to Springfield proper. Thus a population of 127,454 was derived as being representing of the effective population served by the utility. Also, all socio-economic data used in the analysis relate to the 31 census tracts of the urbanized area.

Economy. The economy of the service area is fairly diversified. Average annual per capita income was $9,350 in 1980 dollars. The economic interests include retail and wholesale trade, finance, service and professions, education, government, manufacturing, insurance, medical services, and transportation. Total employment was 63,086 in 1980. The six major employers in the area are the state government (employing 19,200 persons), two hospitals, a manufacturing plant which produces construction equipment, a public school district, and an insurance company which, together with the government employ 30,120 persons.

Principal manufacturers are Fiat-Allis Construction Machinery, Inc., producers of construction equipment; the Pillsbury Co., cake mixes and

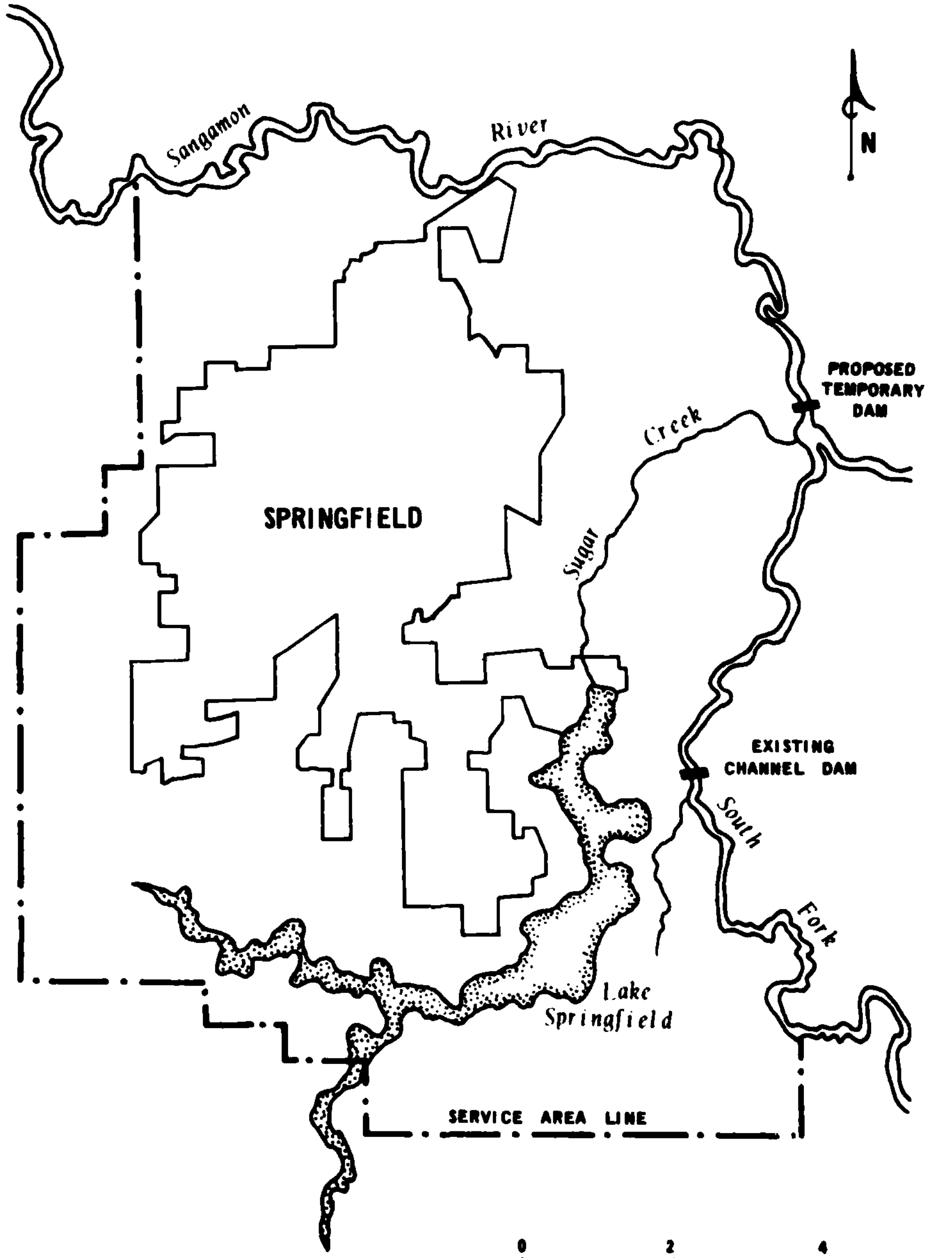


Figure 1. Study Area

flour; John W. Hobbs Division of Stewart-Warner, automotive parts and engine hour meters; Charles C. Thomas, publisher; Phillips Bros. Inc., printing; KWIK-WALL Company, makers of steel storage tanks and Novenco, Inc., fans for coal fired electric generating plants. Industrial employment averaged about 6,500 in 1980.

Water Resources

Total volume of water delivered to the distribution system was 18.9 million gallons per day (mgd) in 1982, and 19.7 mgd in 1980. Raw water is drawn from an artificial lake constructed in 1936. Total storage is 17.2 billion gallons and drains an area of 265 square miles. Water table elevation, at full storage, is 560 feet above mean sea level (MSL) and can be drawn down to 546 feet; below this level water quality becomes unacceptable. The lake is also used as a source for cooling water and as an evaporating pond by the local power plant. The forced evaporation from cooling use can reach up to 6.0 mgd.

The estimated net yield of Lake Springfield is 16.8 mgd for 100-year drought. Yields corresponding to 40- and 25-year droughts are 22.1 and 28.1 mgd, respectively. Fearing that the growing level of demand will not be met during drought, the city is seeking additional sources of supply. The alternatives recommended in engineering reports include the construction of a second lake at a cost of about 38 million dollars and the use of Sangamon River water to supplement storage in the existing lake. A drought management plan is also being formulated which would allow the utility to reduce demand during a shortage situation.

## Types and Sources of Data

The actual kinds and sources of site-specific data which are needed in the preparation of the input information for the DROPS model are shown in Table 1. The major part of these data were obtained during several field trips to Springfield. During these field trips these data were obtained from the following agencies and institutions:

1. Springfield City Water, Light, and Power Department:

   (a) engineering features of the system
   (b) water pumpage records
   (c) billing records
   (d) largest water users.

2. Sangamon County Regional Planning Commission:

   (a) 1980 census summaries
   (b) demographic analysis report
   (c) land use plan (report)
   (d) other documents.

TABLE 1

TYPES AND SOURCES OF DATA

| Data Category | Specific Items | Source |
|---|---|---|
| 1. Operational | Disaggregated historic water use, daily total volumes of water treated and delivered, daily reservoir levels, water and sewer rate structure and revenues for each customer category. | Water utility, state, regional or local planning agencies. |
| 2. Water Resource Utilization | Water use statistics for other than municipal users located in the area (self-supplied industry, agricultural users), especially if they use the same source. | Water utility, interviews with individual users, planning agencies. |
| 3. Hydrographic and Hydrologic | Topographic maps, reservoir rating curves, drainage area(s), streamflow and raw water quality records; hydrologic characteristics of alternative sources including yield estimates, water quality and minimum flow requirements. | U.S. Geological Survey, Environmental Protection Agency, planning agencies. |
| 4. Climate | Precipitation, air temperature, snowfall, soil moisture conditions. | National Weather Service (NOAA). |
| 5. Socio-Economic | Population, household size and income, number of households and housing units, value and size of residential properties, number of commercial and institutional establishments and value of receipts. | U.S. Census of Population, Housing, Business; U.S. Bureau of Labor Statistics. |

TABLE 1 (Continued)

TYPES AND SOURCES OF DATA

| Data Category | Specific Items | Source |
|---|---|---|
| 6. Land-Use | Fractions of land in various use categories (such as urbanized, cropland, woodland), agricultural production statistics. | U.S. Census of Agriculture, planning agencies. |
| 7. Costs | Investment and operation-maintenance costs for alternative water supply sources, operation and maintenance cost of water supply system. | Water utility, consultant Engineering reports, U.S. Environmental Protection Agency reports, U.S. Corps of Engineers, planning agencies. |
| 8. Psychological/ Legal | Acceptability of demand reduction measures by customers, legal/ institutional obstacles. | Literature studies, local government, water utility, interviews of individual customers. |

3. The Greater Springfield Chamber of Commerce Economic Development Council:

   (a) site selection data (package)
   (b) community profile summary
   (c) information on commercial establishments.

4. Crawford, Murphy & Tilly, Inc., Consulting Engineers:

   (a) five engineering reports on water supply improvement

5. Sangamon County Tax Assessor:

   (a) assessed valuation of residences
   (2) lot size.

## Chapter Synopses

This volume of the report is organized around the major steps in the development and evaluation of drought management plans. Chapter II contains an evaluation of the potential water supply deficits which may face the Springfield water utility. The analyses described in that chapter required substantial amounts of data on water use and socio-economic characteristics of the service area. These data were needed for the development of the residential water demand model and disaggregate water use forecast through the year 2020.

Chapters III and IV focus on the evaluation of drought emergency measures. Demand and loss reduction measures are evaluated using a step-by-step analysis of applicability, technical feasibility, social acceptability, effectiveness, implementation conditions, and economic costs. Emergency water supply sources are evaluated with regard to water availability and water quality, adequacy of existing treatment facilities, construction lead time and legal/institutional obstacles.

The drought emergency measures selected in result of this analysis are integrated into alternative shortage mitigation plans in Chapter V. Finally, Chapter V also contains an assessment of the proposed capacity expansion plans in terms of the reduction in costs of mitigation of potential drought-induced water deficits in the future.

## II. DETERMINATION OF POSSIBLE SUPPLY DEFICITS

The objective of this chapter is to determine the magnitude and probability of potential water supply deficits. This is done by comparing the current and the future rates of withdrawal to historical drought records. The alternative drought emergency plans are formulated to match various volumes of these deficits. The following sections describe the steps leading to the determination of the potential deficits.

### Water Supply Availability

For the purpose of this report, the evaluation of the availability of water supply is limited only to the primary source--Lake Springfield. Any additional sources, which may be used during drought, are considered as emergency sources and evaluated in Chapter IV.

The most recent analysis of the reservoir yield for the lake was done by Crawford, Murphy and Tilly, Inc. (CMT) in 1980. The original volume of the lake was 19,888 million gallons. Due to sedimentation, the present volume is about 17,200 million gallons and will decrease to 16,080 mg by the year 2000, if the historical loss of volume of 0.29 percent per year continues. Table 2 gives the estimates of the yield available from Lake Springfield and runoff from its drainage area for a 18-month drought. This length of the critical period was selected by the CMT staff as the duration considered most appropriate for evaluating the risk of water shortage.

As shown in Table 2, the estimated yield of Lake Springfield is 16.8 mgd during the 100-year drought (probability - 0.01) of an 18-month duration. Yields corresponding to 40- and 25-year droughts of the same duration are 22.1 mgd and 28.1 mgd. These yields may be further adjusted downward in order to account for the withdrawals which are used for other purposes. These include: (1) water treatment plant requirements, 0.9 mgd; (2) electric power generation requirements, 4.9 mgd; and (3) allowance of 2.6 mgd for possible future industrial uses and emergency supply for surrounding communities. The 2.6 mgd industrial reserve, however, would not be maintained during drought emergencies.

In 1980 total pumpage of water to the distribution system reached 20 mgd. When compared with the Condition D in Table 2, this level of demand would result in a total deficit of 6.3 mgd during a 40-year drought and 11.6 mgd during a 100-year drought. If the allowance for future industrial use is not maintained then these deficits are 4.3 and 10.3 mgd, respectively. This is only a rough estimation of potential deficits, which, nevertheless, indicates that the possibility of water shortage in Springfield is likely and a more refined analysis of such deficits is warranted.

The sections which follow describe the development of the water demand forecasts for the Springfield urbanized area.

TABLE 2

WATER SUPPLY AVAILABILITY IN LAKE SPRINGFIELD

| Conditions | Year (Silt conditions) | Estimated Net Yield (mgd) for Different Probabilities of Drought 0.10 | 0.04 | 0.025 | 0.01 |
|---|---|---|---|---|---|
| A. Water supply from elev. 560 to 543. | 1980 | -- | 28.1 | 22.1 | 16.8 |
| | 2000 | 43.0 | 25.0 | 21.0 | 15.0 |
| B. After excluding water treatment plant requirements of 0.9 mgd & 1.0 mgd in 1980 and 2000, respectively. | 1980 | -- | 27.2 | 21.2 | 15.9 |
| | 2000 | 42.0 | 24.0 | 20.0 | 14.0 |
| C. After excluding electric power generation requirements of 4.9 mg in 1980 and 4.3 mg in 2000. | 1980 | -- | 22.3 | 16.3 | 11.0 |
| | 2000 | 38.7 | 19.7 | 15.7 | 9.7 |
| D. After excluding the allowance for future industrial use of 2.6 mgd in 1980 and 3.0 mgd in 2000. | 1980 | -- | 19.6 | 13.7 | 8.4 |
| | 2000 | 35.7 | 16.7 | 12.7 | 6.7 |

## Water Demand

As mentioned previously, the area served by the Springfield water systems includes the City of Springfield and the surrounding communities. The latter includes the suburban communities of Grandview, Leland Grove, Jerome, Southern View, Chatham, Rochester, Sherman and Williamsville and unincorporated fringe developments adjacent to Springfield. In the CMT report, the estimated population served in 1970 was 130,000 and it was expected to increase to 144,700 in the year 1980. However, the revised population projections made by the Illinois Bureau of the Budget are considerably adjusted downward, and for the purpose of this study the population served in the base year 1980 was assumed to be represented by the population of the urbanized area, 127,454. Although this population does not include some of the bulk sale customers, the decision to use the urbanized area to approximate the service area was also dictated by the availability of socio-economic data for this political subdivision. This area includes four separate communities plus unincorporated areas adjacent to Springfield, all covered by 31 census tracts.

### IWR MAIN Disaggregation of Water Demand

Application of the DROPS model requires water use data and demand forecasts which are disaggregated by various customer categories. Since such information was not available for Springfield, the current and future water use in the study area was determined using the computerized forecasting system IWR MAIN. This system estimates water use at a highly disaggregate level based on socio-economic characteristics of the area for the base year supplemented by selected historical data. The IWR MAIN System takes into account four water use sectors: residential, commercial/institutional, industrial, and public and unaccounted water uses.

Data collection. The input information to the IWR MAIN model includes four different subsets of data: (1) general information; (2) municipal data for residential, commercial, industrial, and public/unaccounted categories; (3) local historical data; and (4) projection data. Table 3 lists both the general and specific data which are required by the model. The data values, obtained from the various sources discussed in the previous chapter, are listed in Tables 4 and 5.

Results of the IWR MAIN analysis. The results of the IWR MAIN analysis were used primarily to disaggregate total municipal water use. Table 6 gives a summary of the municipal water requirements for the year 1980. Further disaggregation of water usage by the IWR MAIN System is presented in Tables 7 and 8. The IWR MAIN estimate of 20.3 mgd closely corresponds the actual pumpage of 19.7 mgd for that year.

TABLE 3

LIST OF INPUT INFORMATION TO IWR MAIN SYSTEM

I. BASE YEAR GENERAL DATA

- CDAT - Calendar year of current parameter values provided
- LATD - Latitude of urban area being studied
- LONG - Longitude of urban area being studied
- POPU - Population of study area in base year
- PDEN - Gross population density of study area in base year
- POPP - Fraction of the population which is in the 20 to 39 year age group in the base year
- EMPL - Total employment within the study area in the base year
- EMTC - Total employment within the study area in the transportation, communications and utilities industries
- ICOM - Per capita personal income of population residing within study area expressed in 1980 dollars
- TSER - Total employment in service industries within the study area for the base year
- CCBN - Department of Commerce National Composite Construction Cost Index for the base year

II. BASE YEAR MUNICIPAL DATA

1. Residential

- ANPR - Marginal price of water, cents
- SMPR - Marginal seasonal price of water
- ASMT - Assessment factor
- DENS - Housing density expressed in dwelling units per residential acre
- VALN - Lower limit of a property value range
- VALX - Upper limit of a property value range
- NUMB - Number of occupied housing units

TABLE 3 (Continued)

LIST OF INPUT INFORMATION TO IWR MAIN SYSTEM

2. Commercial and Institutional Data

HOTL - Hotel area, sq. ft.
MOTL - Motel area, sq. ft.
BARB - Barber shop chairs, number
BEUT - Beauty salon stations, number
EATN - Restaurant seats, number
EATO - Drive-in restaurant stalls, number
NITE - Night clubs, persons served
HOSP - Hospital beds, number
NURS - Nursing home beds, number
MEDL - Medical offices, sq. ft.
LNDY - Laundry, sq. ft.
LNDM - Laundromats, sq. ft.
SALE - Retail space, sq. ft.
DPOT - Bus-Rail depots, sq. ft.
CARW - Car washes, inside sq. ft.
CHUR - Churches, member
CLUB - Golf-swim clubs, member
BOWL - Bowling alleys, alley
COLG - College residents, student
MOVI - Drive-in movies, car stalls
OFFN - New office buildings, area sq. ft.
OFFO - Old office buildings, area sq. ft.
JAIL - Jail and prison, person
THTR - Theaters, seat
YMCA - YMCA and YWCA, person
GASS - Service stations, inside sq. ft.
COO1 - Apartments, occupied units
COO2 - Fast food restaurants, establishments

TABLE 3 (Continued)

LIST OF INPUT INFORMATION TO IWR MAIN SYSTEM

3. Industrial Data

I201 - Meat products, employment
.
.
.
I399 - Miscellaneous manufacturing, employment

4. *Public/Unaccounted* Data

A1RP - Average number of passengers/day
LOSS - Distribution water loss, gpd
FSER - Free service water, gpd

III. LOCAL HISTORICAL DATA

1. General

POPULATN - Resident population in number of persons
ALLHOMES - Number of occupied residential units
MEDHOMES - Fraction of single-unit owner-occupied residences in medium value range ($25,500-$50,999)
HIGHOMES - Fraction of a single-unit owner-occupied residence in high value range ($51,000 and greater)
SKOLYEAR - Number of school years completed by persons 25 years and older
ELEMSKOL - Elementary (grades K-8) school enrollment
HIGHSKOL - High (grades 9-12) school enrollment
TSERVICE - Total services employment (S.I.C. 700-899)
MEDICALS - Medical services employment (S.I.C. 800-809)

TABLE 3 (Continued)

LIST OF INPUT INFORMATION TO IWR MAIN SYSTEM

2. Industrial History (INDHISTY)

| | | |
|---|---|---|
| YEAR | - | Calendar year |
| POPU | - | Number of persons in study or employment area |
| ICOM | - | Per capita income in study or employment area |
| EMPL | - | Total employment in study or employment area |
| I200 | - | S.I.C. 200-209, Food and kindred products, employment |
| I210 | - | Tobacco products, employment |
| I220 | - | Textile mill products, employment |
| I230 | - | Apparel and other textile products, employment |
| I240 | - | Lumber and wood products, employment |
| I250 | - | Furniture and fixtures, employment |
| I260 | - | Paper and allied products, employment |
| I270 | - | Printing and publishing, employment |
| I300 | - | Chemical and allied products, employment |
| I330 | - | Primary metal industries, employment |
| I340 | - | Fabricated metal products, employment |
| I370 | - | Transportation equipment, employment |
| I400 | - | Adminstrative and auxiliary employment |

IV. PROJECTION DATA (NEWYEAR)

| | | |
|---|---|---|
| YEAR | - | Future calendar year |
| POPU | - | Projected population |
| ICOM | - | Per capita personal income |
| ACRE | - | Acres of residential land |
| DENS | - | Number of units/gross residential acre |
| TSER | - | Persons employed S.I.C. 700-899 |
| MWTL | - | Total number of housing units |
| SKLL | - | Elementary school enrollment |
| SKLH | - | High school enrollments |
| CØØ1 | - | Apartments |

Table 4. IWR MAIN INPUT DATA, CITY AND RESIDENTIAL

```
CITYDATA
SPRINGFIELD URBAN AREA
CDAT      1980.000
LATD        40.000
LONG        89.000
POPU    127454.000
PDEN      5098.000
POPP          .328
EMPL     63086.000
EMTC      3965.000
ICOM      9350.000
TSER     12745.000
CCBN       143.200
ENDD
METRSEWR
VALN     10000.000
VALX     14999.000
ANPR       109.000
DENS        37.000
NUMB      3058.000
SMPR       109.000
VALN     15000.000
VALX     19999.000
ANPR       109.000
DENS        37.000
NUMB      5679.000
SMPR       109.000
VALN     20000.000
VALX     24999.000
ANPR       109.000
DENS        11.000
NUMB      6485.000
SMPR       109.000
VALN     25000.000
VALX     29999.000
ANPR       109.000
DENS         8.000
NUMB      4922.000
SMPR       109.000
VALN     30000.000
VALX     34999.000
ANPR       109.000
DENS         7.000
NUMB      3560.000
SMPR       109.000
VALN     35000.000
VALX     39999.000
ANPR       109.000
DENS         5.000
NUMB      3114.000
SMPR       109.000
VALN     40000.000
VALX     49999.000
ANPR       109.000
DENS         3.000
NUMB      5368.000
SMPR       109.000
VALN     50000.000
VALX     59999.000
ANPR       109.000
DENS         2.000
NUMB      3616.000
SMPR       109.000
VALN     60000.000
VALX     79999.000
ANPR       109.000
DENS         1.500
NUMB      4003.000
SMPR       109.000
VALN     80000.000
VALX     99999.000
ANPR       109.000
DENS         1.200
NUMB      1395.000
SMPR       109.000
VALN    100000.000
VALX    149999.000
ANPR       109.000
DENS         1.000
NUMB       733.000
SMPR       109.000
VALN    150000.000
VALX    199999.000
ANPR       109.000
DENS          .800
NUMB       175.000
SMPR       109.000
```

Table 5. IWR MAIN INPUT DATA, COMMERCIAL AND INDUSTRIAL PARAMETERS

| | |
|---|---|
| [illegible] | |
| [illegible] | [illegible] |
| [illegible] | 88348.000 |
| [illegible] | [illegible] |
| [illegible] | [illegible] |
| [illegible] | [illegible] |
| [illegible] | [illegible] |
| [illegible] | [illegible] |
| [illegible] | [illegible] |
| [illegible] | [illegible] |
| [illegible] | [illegible] |
| [illegible] | [illegible] |
| SALE | 404[illegible]6.000 |
| SELE | [illegible] |
| SALH | [illegible] |
| BEAU | 9433[illegible].000 |
| CARW | [illegible]566.000 |
| CHUR | 57354.000 |
| CLUB | 10930.000 |
| BOWL | 142.000 |
| COLS | 1966.000 |
| MOVI | 3400.000 |
| OFFN | 1780125.000 |
| OFFO | 1338858.000 |
| JAIL | 180.000 |
| THTR | 5336.000 |
| YMCA | 13000.000 |
| GASS | 94332.000 |
| C001 | 12263.000 |
| C002 | 41.000 |
| ENDD | |

| | |
|---|---|
| INDPGRAM | |
| 1208 | 466.000 |
| 1209 | 30.000 |
| 1230 | 32.000 |
| 1251 | 48.000 |
| 1270 | 688.000 |
| 1281 | 22.000 |
| 1282 | 300.000 |
| 1287 | 34.000 |
| 1291 | 40.000 |
| 1307 | 66.000 |
| 1327 | 205.000 |
| 1344 | 48.000 |
| 1352 | 72.000 |
| 1353 | 1775.000 |
| 1358 | 225.000 |
| 1361 | 50.000 |
| 1364 | 200.000 |
| ENDD | |

TABLE 6

**IWR MAIN MUNICIPAL WATER REQUIREMENTS REPORT**

SUMMARY OF MUNICIPAL WATER REQUIREMENTS FOR CITY OF SPRINGFIELD URBAN AREA

ESTIMATED WATER REQUIREMENTS FOR YEAR 1980.
(ALL VALUES IN GALLONS PER DAY)

| | ANNUAL AVERAGE | MAXIMUM DAILY | PEAK HOURLY |
|---|---|---|---|
| MUNICIPAL | 20270572. | 31522316. | 66248261. |
| RESIDENTIAL | 9064748. | 20316492. | 55042437. |
| COMMERCIAL | 6904445. | 11066929. | 25796355. |
| INDUSTRIAL | 1739553. | 1739553. | 1739553. |
| PUBLIC AND UNACC. | 2561825. | 2561825. | 2561825. |

**TABLE 7**

**IWR MAIN RESIDENTIAL WATER USE REPORT**

MUNICIPAL WATER REQUIREMENTS FOR THE CITY OF SPRINGFIELD URBAN AREA FOR 1980

ANALYZED BY MAIN SYSTEM

CURRENT RESIDENTIAL WATER REQUIREMENTS BY CATEGORY

METERED AND SEWERED AREAS

| VALUE RANGE ($) | NO. OF UNITS | ANNUAL AVERAGE DOMESTIC | ANNUAL AVERAGE SPRINKLING | ANNUAL AVERAGE TOTAL | MAX DAY | PEAK HOUR |
|---|---|---|---|---|---|---|
| 10000 - 14999 | 3058 | 508543. | 100513. | 609056. | 732095. | 2498007. |
| 15000 - 19999 | 5679 | 969861. | 304054. | 1273915. | 1537749. | 4998426. |
| 20000 - 24999 | 6485 | 1136570. | 148756. | 1285326. | 2117962. | 6437920. |
| 25000 - 29999 | 4922 | 884692. | 109872. | 994564. | 1826095. | 5327182. |
| 30000 - 34999 | 3560 | 655836. | 88604. | 744439. | 1467267. | 4148518. |
| 35000 - 39999 | 3114 | 587626. | 68144. | 655770. | 1440152. | 3944862. |
| 40000 - 49999 | 5368 | 1049048. | 91848. | 1140896. | 2927951. | 7698589. |
| 50000 - 59999 | 3616 | 739068. | 55196. | 794264. | 2359532. | 5966919. |
| 60000 - 79999 | 4003 | 871980. | 65027. | 937007. | 3215570. | 7822806. |
| 80000 - 99999 | 1395 | 328879. | 26104. | 354984. | 1395704. | 3281065. |
| 100000 - 149999 | 733 | 195801. | 18408. | 214209. | 977824. | 2217094. |
| 150000 - 199999 | 175 | 54588. | 5728. | 60316. | 318591. | 701048. |
| TOTAL | 42108 | 7982495. | 1082253. | 9064748. | 20316492. | 55042437. |

Table 8. **IWR MAIN COMMERCIAL WATER USE REPORT**

WATER REQUIREMENTS BY TYPE OF COMMERCIAL ESTABLISHMENT

| TYPE | UNITS | NUMBER OF UNITS | ANNUAL AVERAGE | MAXIMUM DAILY | PEAK HOURLY |
|---|---|---|---|---|---|
| | | | (GALLONS PER DAY) | | |
| HOTELS | SQ. FT. | 129136. | 33059. | 37966. | 55916. |
| MOTELS | SQ. FT. | 888448. | 199012. | 409575. | 1377094. |
| BARBER SHOPS | BARBER CHAIR | 112. | 6115. | 8994. | 43568. |
| BEAUTY SHOPS | STATION | 402. | 108138. | 131856. | 430140. |
| RESTAURANTS | SEAT | 15990. | 386958. | 1333566. | 2670330. |
| NIGHT CLUBS | PERSON SERVED | 1605. | 2135. | 2135. | 2135. |
| HOSPITALS | BED | 1629. | 563634. | 897579. | 1485648. |
| NURSING HOMES | BED | 1881. | 250173. | 274626. | 797544. |
| MEDICAL OFFICES | SQ. FT. | 300722. | 185846. | 499199. | 1494588. |
| LAUNDRY | SQ. FT. | 106265. | 26885. | 34642. | 166836. |
| LAUNDROMATS | SQ. FT. | 42390. | 91986. | 200929. | 275959. |
| RETAIL SPACE | SALES SQ. FT. | 3045896. | 322865. | 469068. | 825438. |
| SCHOOL,ELEM. | STUDENT | 15025. | 80835. | 145442. | 737728. |
| SCHOOL, HIGH | STUDENT | 7825. | 51880. | 153370. | 946825. |
| BUS-RAIL DEPOTS | SQ. FT. | 94332. | 314126. | 613158. | 2358300. |
| CAR WASHES | INSIDE SQ. FT. | 22566. | 107865. | 232430. | 710829. |
| CHURCHES | MEMBER | 57354. | 7915. | 49439. | 269564. |
| GOLF-SWIM CLUBS | MEMBER | 10930. | 338830. | 242646. | 242646. |
| BOWLING ALLEYS | ALLEY | 142. | 18886. | 18886. | 18886. |
| COLLEGES RESID. | STUDENT | 1966. | 208396. | 224124. | 491500. |
| DRIVE-IN MOVIES | CAR STALL | 3400. | 17000. | 18122. | 18122. |
| NEW OFFICE BLDG | SQ. FT. | 1780125. | 165552. | 307962. | 927445. |
| OLD OFFICE BLDG | SQ. FT. | 1338858. | 190118. | 108447. | 473956. |
| JAIL & PRISONS | PERSON | 180. | 23940. | 23940. | 23940. |
| THEATERS | SEAT | 5336. | 17769. | 17769. | 17769. |
| YMCA-YWCA FACIL | PERSON | 13000. | 432900. | 432900. | 432900. |
| SERVICE STATION | INSIDE SQ. FT. | 94332. | 23677. | 55656. | 2971458. |
| APARTMENTS | OCCUPIED UNITS | 12233. | 2654561. | 3975725. | 5309122. |
| FAST FOOD REST. | ESTABLISHMENT | 41. | 73390. | 146780. | 220170. |

TOTAL COMMERCIAL REQUIREMENTS IN GALLONS PER DAY

| ANNUAL AVERAGE | MAXIMUM DAILY | PEAK HOURLY |
|---|---|---|
| 6904445. | 11066929. | 25796355. |

## Water Use Forecast

Future water use in the service area was initially determined using the IWR MAIN System. However, the estimates of the future demand in residential and commercial user categories were revised due to concerns related to the reliability of the internal growth models used in the IWR MAIN System. These models were developed in late 1960s and may not produce accurate estimates under today's conditions. The methods used to develop the revised forecasts for residential and commercial sectors are presented below.

### Residential Water Use Forecast

Residential water use in 1980 was estimated by the IWR MAIN System at 9.1 mgd (Table 7). However, the 42,108 residential units used in this forecast do not include all units in the area. The 1980 Census report gives the totals for the urbanized area as follows:

| | | |
|---|---|---|
| Single family units | - | 33,920 |
| Multiple dwelling units | - | 12,233 |
| Mobile homes | - | 2,026 |
| Total | | 48,179 |

The multiple dwelling units are included in the IWR MAIN System in the commercial sector as apartments. Therefore the total domestic water usage should be increased by 2.7 mgd shown in the apartments category of commercial users in Table 8. The revised residential water use forecast shown in Table 9 uses both the single and multiple units. It was developed based on the total number of units in each group and the average water use per unit. The future estimates of the number of housing units were developed by Sangamon County Regional Planning Commission (SCRPC) for the years 1990 and 2000. Forecasts for the years 2010 and 2020 were projected proportionately to population projections while maintaining the same mix of single and multiple units. Table 9 does not include water usage by mobile home parks. These are included as a separate category of commercial users.

The forecasts of the number of homes and apartments and population projections were developed by the SCRPC, however, these forecasts were available only through the year 2000. The Illinois Bureau of the Budget forecast for the Sangamon County was used to determine the population growth in the urbanized area beyond the year 2000. The number of housing units in the years 2010 and 2020 were determined based on the assumption of constant number of persons per housing unit.

The unit water use coefficients per housing unit were determined using the billing records made available through the City Water, Light and Power (CWLP). Based on a random sample of 105 residential customers, it was found that the average annual water usage in 1982 was 188 gallons per day per customer. This estimate was used in projecting future water use by single family housing units, and mobile homes. Individual apartments in multiple housing units are not metered, but comparison between number of units and average annual water use by multiple units accounts yielded an average use of 296 gallons per apartment per day. This estimate was used in predicting future water use by apartments.

TABLE 9

RESIDENTIAL WATER DEMAND FORECAST[a]

| | 1980 | 1990 | 2000 | 2010 | 2020 |
|---|---|---|---|---|---|
| A. Population | 127,000 | 134,000 | 139,000 | 146,000 | 162,000 |
| B. Single residential units | 34,000 | 39,000 | 51,000 | 53,000[b] | 59,000 |
| C. Multiple dwelling units | 12,000 | 15,000 | 19,000 | 20,000[b] | 22,000[b] |
| D. Water use, single units, B x 188 gpd | 6,377,000 | 7,302,000 | 9,554,000 | 10,029,000 | 11,142,000 |
| E. Water use multiple units, C x 296 gpd | 3,621,000 | 4,493,000 | 5,524,000 | 5,842,000 | 6,491,000 |
| F. Total residential use, D + E, gpd | 9,998,000 | 11,796,000 | 15,078,000 | 15,871,000 | 17,633,000 |
| G. Per capita use, gpcd, F/A | 78.4[c] | 88.0 | 108.4 | 108.7 | 108.7 |

[a] Projections based on number of housing units and constant use per dwelling unit
[b] Projected proportionately to population forecast
[c] Calculated only for comparative purposes.

## Commercial Water Use Forecast

The disaggregation of commercial water use into 29 categories, including apartments, by the IWR System shows the estimated total commercial use in 1980 approximating 6.9 mgd (Table 8). The estimates of water usage by each commercial subgroup are developed based on unit use coefficients. Future water requirements by commercial users could not be determined by the IWR MAIN System due to the lack of future employment data for the commercial sector. Therefore, the commercial forecast was developed manually using the available population projections and linear regression equations for predicting the number of units in each category developed by Thompson et al (1976). The results of this forecast are shown in Table 10.

## Other Sectors

Water use in industrial and public/unaccounted sectors were prepared using the IWR MAIN System and are summarized in Tables 11 and 12. The industrial forecast used the employment estimates shown in Table 5 supplemented by historical data on employment in these SIC categories obtained from the 1960 and 1970 census reports. Public/unaccounted water use was estimated using parameter values provided by the IWR MAIN System. Finally, the remaining categories shown in Table 13 are water purchased by the power station as make-up and domestic water. The total usage in 1982 was 868,000 gpd and was assumed to represent the 1980 estimate. Future purchases by the power station were adjusted in proportion to the predicted station total water use in the future obtained through the CMT report.

## Discussion of the Results of the Forecast

The forecast of future water use presented in Table 13 shows a moderate increase in total use by the year 1990 and a 4.6 mgd increase between the years 1990 and 2000. These estimates may be judged as optimistic in comparison to the forecast of future use developed by CMT. Using effective population estimates of 155,200 persons in 1990 and 169,700 in 2000, the CMT staff produced estimates of 22.6 mgd and 25.1 mgd, respectively. These estimates were calculated using the per capita method and assuming 125 gpcd in 1990 and 127 gpcd in the year 2000. There is a substantial discrepancy between the estimate of the population served used in the CMT study and the estimates used in this report. The assumed service area (urbanized area) used here has understandably smaller population than the total population including all the communities which are presently served or may be served in the future by the CWLP. This implies that in order to compare the CMT forecast and the present forecast, it is necessary to increase our estimates in order to account for growth in sales to communities located outside the urbanized area.

TABLE 10

COMMERCIAL WATER DEMAND FORECAST

| Type of Establishment | Annual Average Usage in gpd 1980 | 1990 | 2000 | 2010 | 2020 |
|---|---|---|---|---|---|
| HOTL | 33,000 | 35,000 | 36,000 | 37,000 | 41,000 |
| MOTL | 199,000 | 210,000 | 219,000 | 230,000 | 258,000 |
| BARB | 6,000 | 7,000 | 7,000 | 7,000 | 8,000 |
| BEUT | 108,000 | 114,000 | 119,000 | 125,000 | 139,000 |
| EATN | 387,000 | 407,000 | 423,000 | 444,000 | 493,000 |
| NITE | 2,000 | 3,000 | 3,000 | 3,000 | 4,000 |
| HOSP | 564,000 | 582,000 | 597,000 | 617,000 | 664,000 |
| NURS | 250,000 | 255,000 | 258,000 | 261,000 | 271,000 |
| MEDL | 186,000 | 201,000 | 209,000 | 219,000 | 243,000 |
| LNDY | 27,000 | 28,000 | 29,000 | 31,000 | 34,000 |
| LNDM | 92,000 | 97,000 | 100,000 | 105,000 | 117,000 |
| SALE | 323,000 | 327,000 | 339,000 | 357,000 | 375,000 |
| SKLL | 81,000 | 107,000 | 111,000 | 117,000 | 130,000 |
| SKLH | 52,000 | 66,000 | 69,000 | 72,000 | 80,000 |
| DPOT | 30,000 | 30,000 | 31,000 | 31,000 | 33,000 |
| CARW | 108,000 | 113,000 | 117,000 | 122,000 | 135,000 |
| CHUR | 8,000 | 8,000 | 9,000 | 9,000 | 10,000 |
| CLUB | 339,000 | 357,000 | 370,000 | 389,000 | 433,000 |
| BOWL | 19,000 | 19,000 | 19,000 | 20,000 | 21,000 |
| COLG | 208,000 | 214,000 | 218,000 | 224,000 | 238,000 |
| MOVI | 17,000 | 17,000 | 17,000 | 17,000 | 17,000 |
| OFFN | 165,000 | 176,000 | 184,000 | 196,000 | 222,000 |
| OFFO | 190,000 | 200,000 | 207,000 | 218,000 | 242,000 |
| JAIL | 24,000 | 25,000 | 26,000 | 27,000 | 30,000 |
| THTR | 18,000 | 18,000 | 19,000 | 20,000 | 22,000 |
| YMCA | 433,000 | 443,000 | 453,000 | 466,000 | 497,000 |
| GASS | 24,000 | 25,000 | 26,000 | 27,000 | 30,000 |
| FASTFOOD | 73,000 | 77,000 | 81,000 | 86,000 | 93,000 |
| MHP[a] | 381,000 | 444,000 | 573,000 | 603,000 | 670,000 |
| SIC721 | 67,000 | 104,000 | 147,000 | 200,000 | 278,000 |
| Total | 4,414,000 | 4,709,000 | 5,016,000 | 5,278,000 | 5,826,000 |

[a]At 188 gpd/trailer

## TABLE 11

## IWR MAIN INDUSTRIAL WATER USE REPORT

MUNICIPAL WATER REQUIREMENTS FOR THE CITY OF SPRINGFIELD URBAN AREA FOR 1980

ANALYZED BY MAIN SYSTEM

TOTAL INDUSTRIAL WATER REQUIREMENTS IN GALLONS PER DAY

| ANNUAL AVERAGE | MAXIMUM DAILY | PEAK HOURLY |
|---|---|---|
| 1739553. | 1739553. | 1739553. |

REQUIREMENTS BY TYPE OF INDUSTRY

| CATEGORY | | NUMBER OF EMPLOYEES | GALLONS/DAY ANNUAL AVERAGE | MAXIMUM DAY | PEAK HOUR |
|---|---|---|---|---|---|
| 208 | BEVERAGES | 466. | 533508. | 533508. | 533508. |
| 209 | MISCELL. FOODS | 30. | 32321. | 32321. | 32321. |
| 230 | WHL.APPAREL IND. | 32. | 640. | 640. | 640. |
| 251 | HOME FURNITURE | 48. | 5865. | 5865. | 5865. |
| 270 | WHOL.PRINT IND. | 688. | 10320. | 10320. | 10320. |
| 281 | BASIC CHEMICALS | 22. | 60377. | 60377. | 60377. |
| 282 | FIBERS, PLASTICS | 300. | 259468. | 259468. | 259468. |
| 287 | AGRICULTURE CHEM | 34. | 15294. | 15294. | 15294. |
| 291 | PETROLEUM REFIN. | 40. | 125644. | 125644. | 125644. |
| 307 | PLASTIC PRODUCTS | 66. | 34834. | 34834. | 34834. |
| 327 | CEMENT-PLASTER | 205. | 72526. | 72526. | 72526. |
| 344 | STRUCTURE METAL | 49. | 15354. | 15354. | 15354. |
| 352 | FARM MACHINERY | 72. | 23091. | 23091. | 23091. |
| 353 | CONSTRUCT. EQUIP | 1775. | 387598. | 387598. | 387598. |
| 358 | SERV. IND. MACH. | 225. | 75196. | 75196. | 75196. |
| 361 | ELECT.DISTR.PROD | 50. | 13600. | 13600. | 13600. |
| 364 | LIGHT-WIRING FIX | 200. | 73918. | 73918. | 73918. |

# TABLE 12

## IWR MAIN PUBLIC/UNACCOUNTED WATER USE

MUNICIPAL WATER REQUIREMENTS FOR THE CITY OF SPRINGFIELD URBAN AREA FOR 1980

ANALYZED BY MAIN SYSTEM

TOTAL PUBLIC-UNACCOUNTED REQUIREMENTS IN GALLONS PER DAY

| ANNUAL AVERAGE | MAXIMUM DAILY | PEAK HOURLY |
|---|---|---|
| 2561825. | 2561825. | 2561825. |

REQUIREMENTS BY TYPE OF PUBLIC-UNACCOUNTED USAGE IN GALLONS PER DAY

| TYPE | ANNUAL AVERAGE | MAXIMUM DAILY | PEAK HOURLY |
|---|---|---|---|
| DISTRIB. LOSSES | 1899065. | 1899065. | 1899065. |
| FREE SERVICES | 662761. | 662761. | 662761. |

TABLE 13

SUMMARY OF MUNICIPAL WATER USE FORECAST FOR SPRINGFIELD

| Category | Estimated Water Requirements, GPD | | | | |
|---|---|---|---|---|---|
| | 1980 | 1990 | 2000 | 2010 | 2020 |
| Domestic[a] | 9,998,000 | 11,796,000 | 15,078,000 | 15,872,000 | 17,633,000 |
| Commercial/Institutional[b] | 4,413,000 | 4,711,000 | 5,015,000 | 5,281,000 | 5,828,000 |
| Industrial[c] | 1,739,000 | 2,707,000 | 3,823,000 | 5,196,000 | 7,212,000 |
| Power Station Purchases[d] | 867,000 | 605,000 | 342,000 | 300,000 | 300,000 |
| Public/Unaccounted[c] | 2,562,000 | 2,695,000 | 2,876,000 | 2,934,000 | 3,259,000 |
| Municipal (Total) | 19,579,000 | 22,513,000 | 27,134,000 | 29,583,000 | 34,231,000 |

[a]From Table 9
[b]From Table 10
[c]Determined by IWR MAIN system
[d]Purchases adjusted proportionately to predicted station use of water

## Potential Water Supply Deficits

The availability of water supply during drought presented in Table 2 extends only through the year 2000. The available yield of the lake in the year 2010 and 2020 will be further diminished due to siltation at a rate of 0.29 percent of total volume per year. Assuming linear decrease in lake capacity and the available yield with time, the estimates of the available yield during droughts of different probabilities of occurrence are shown in Table 14. The projected deficits for the future years are calculated after subtracting water treatment plant requirements, electric power generation requirements, and municipal water demand. Row E in Table 14 shows the magnitude of deficits during droughts with the probabilities of occurrence ranging from 0.10 (10-year drought) to 0.01 (100-year drought). They indicate that during 40-year drought the deficit of water supply from the lake would have been 3.3 mgd in 1980 and increase to 20 mgd in the year 2020.

Although these deficits are calculated based on relatively sound assumptions, it should be realized that they are not likely to occur because the Springfield system has additional emergency supply sources which will be used to make-up for these deficits. The following chapters describe an analysis designed to determine the most efficient ways of alleviating these deficits, although not necessarily through auxiliary pumping.

TABLE 14

POTENTIAL DEFICITS IN WATER SUPPLY FROM LAKE SPRINGFIELD

| | Probability P | Years: 1980 | 1990 | 2000 | 2010 | 2020 |
|---|---|---|---|---|---|---|
| A. Water supply during 18-mo. drought, mgd | 0.10 | (48.0)[a] | (45.5) | 43.0 | (40.5) | (38.0) |
| | 0.04 | 28.1 | (27.5) | 25.0 | (24.2) | (23.3) |
| | 0.025 | 22.1 | (21.5) | 21.0 | (20.3) | (19.5) |
| | 0.01 | 16.8 | (15.9) | 15.0 | (14.5) | (13.9) |
| B. Water treatment plant requirements, mgd | | 0.9 | 0.9 | 1.0 | (1.0) | (1.0) |
| C. Electric power gen. requirements, mgd | | 4.9 | (4.6) | 4.3 | (4.3) | (4.3) |
| D. Municipal water demand forecast, mgd (from Table 13) | | 19.6 | 22.5 | 27.1 | 29.6 | 34.2 |
| E. Projected deficits, A-(B+C+D) mgd | 0.10 | +22.6 | +17.5 | +10.6 | + 5.6 | - 1.5 |
| | 0.04 | + 2.7 | - 0.5 | - 7.4 | -10.7 | -16.2 |
| | 0.025 | - 3.3 | - 6.5 | -11.4 | -14.6 | -20.0 |
| | 0.01 | - 8.6 | -12.1 | -17.4 | -20.4 | -25.6 |

[a]Numbers in parenthesis represent either linear approximations or assumed values of available water supply prepared for use in this study only.

## III. EVALUATION OF DEMAND AND LOSS REDUCTION MEASURES

This chapter identifies the demand and loss reduction measures that can be applied by the Springfield water supply system during drought. An array of demand and loss reduction measures is evaluated step-by-step with regard to such determinations as social acceptability, effectiveness, implementation conditions and implementation costs. Also the economic losses to the study area which may result from the implementation of demand reduction measures are assessed.

### Formulation of Feasible Measures

#### Evaluation of Applicability, Technical Feasibility and Social Acceptability

The purpose of this step of evaluation is to prepare an array of applicable, technically feasible and socially acceptable demand and loss reduction measures. The first step is to prepare an initial list of various measures like the one shown in Table 15 (this table also appears on page 39 of the first volume of this report). Measures included on this list were examined for their applicability to the study area during drought emergency situations. Next, all applicable measures are tested for their capability of producing a measurable reduction in water use. Finally, the applicable and technically feasible measures must be evaluated with respect to the various sectors of the community.

The initial evaluation of potential demand and loss reduction measures led to the selection of measures presented in Table 16. The staff of the water utility felt that these measures are applicable, technically feasible and they would be either acceptable or potentially acceptable by the residents of the area. These broadly defined measures must be further analyzed for implementation conditions.

#### Implementation Conditions and Effectiveness

Some of the measures in Table 16 need to be defined more narrowly or subdivided into several parts, each constituting a separate measure. In addition, a specific measure, for example, Measure M5 (restrictions on nonessential uses) may be alternately defined as lasting for 1, 2, 3, or 6 months and then it will be treated as three different measures. Similarly, both sectoral and temporal coverage for each measure may be defined.

Subsequently, one or more of the narrowly defined demand reduction measures will be assembled into "packages" to be implemented at the same time to achieve a desired reduction in water use. The measures intended for simultaneous implementation are referred to as demand and loss reduction programs.

In addition to implementation conditions it is necessary to determine the effectiveness of each of the individual measures, i.e., the reduction



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TABLE 15

LIST OF DEMAND AND LOSS REDUCTION MEASURES

1. EDUCATION

Direct Mail:
pamphlets, leaflets, posters, bill inserts, newsletters, handbooks, buttons, bumper stickers

News media:
radio/TV ads and announcements, newspaper articles, movies

Personal contact:
speaker programs, slide shows, booths at fairs, customer assistance

Special events:
school talks, slogan/poster contests, posters around town, billboards, displays, decals, water served only on request

2. TECHNOLOGY

Domestic indoor:
water closet inserts, shower flow-control devices, water conservation kits, reuse recycle systems, faucet flow restrictors

Domestic outdoor:
moisture sensors, hose meters, sprinkling timers, swimming pool covers

3. RATIONING

Mandatory:
fixed allocation, per capita, per household, prior use, variable percentage plan, inconvenience

Pricing:
drought surcharge, seasonal use charge, excess use charge, penalties

4. RESTRICTIONS/BANS

Domestic indoor/outdoor:
lawn sprinkling, car washing, pool filling, pavement hosing, air conditioning

Public/institutional:
street cleaning, public fountains, landscape irrigation, shortened school day and office hours

TABLE 15 (Continued)

LIST OF DEMAND AND LOSS REDUCTION MEASURES

Industrial/commercial:
car washes, limited time of operation, recycling

5. SYSTEM MODIFICATIONS

Raw water source:
evaporation suppression, reduced dam leaks, deepened wells, surged and cleaned wells, surplus water transfers

Treatment plant:
recirculation of washwater, blending impaired quality water

Distribution system:
pressure reduction, leak detection and repair, discontinued hydrant and main flushing

TABLE 16

FEASIBLE DEMAND AND LOSS REDUCTION MEASURES

| Measure Definition | Effectiveness Information[a] Affected Sector | R | C (modest, moderate, maximum) | | |
|---|---|---|---|---|---|
| M1. Public information campaign coupled with appeals for voluntary conservation | SFO | 0.089 | 0.25 | 0.50 | 0.90 |
| | SFI | 0.089 | 0.50 | 0.75 | 0.90 |
| | MF | 0.089 | 0.50 | 0.75 | 0.90 |
| | COM | 0.089 | 0.25 | 0.50 | 0.75 |
| | IND | 0.089 | 0.25 | 0.50 | 0.75 |
| | PUB | 0.089 | 0.50 | 0.75 | 1.00 |
| M2. Distribution of low flow showerheads | MF | 0.143 | 0.20 | 0.40 | 0.70 |
| | SFI | 0.143 | 0.20 | 0.40 | 0.70 |
| | PUB | 0.143 | 0.10 | 0.20 | 0.33 |
| M3. Distribution of displacement devices | SFI | 0.120 | 0.25 | 0.50 | 0.90 |
| | MF | 0.120 | 0.25 | 0.50 | 0.90 |
| | COM | 0.120 | 0.25 | 0.50 | 0.90 |
| | PUB | 0.120 | 0.25 | 0.50 | 0.90 |
| M4. Water pricing policy (rate surcharge 30 or 50% of the total bill) | SFO | | | | |
| | SFI | $R = [1-(P_2/P_1)^e]$ | | | |
| | MF | | | | |
| | COM | $C = 1.00$ | | | |
| | IND | | | | |
| M5. Restrictions on nonessential water uses | SIO | 0.237 | 0.50 | 0.75 | 1.00 |
| | COM | 0.213 | 0.50 | 0.75 | 1.00 |
| | IND | 0.159 | 0.50 | 0.75 | 1.00 |
| | PUB | 0.213 | 1.00 | 1.00 | 1.00 |

TABLE 16 (Continued)

FEASIBLE DEMAND AND LOSS REDUCTION MEASURES

| Measure Definition | Effectiveness Information[a] Affected Sector | R | C (modest, moderate, maximum) |
|---|---|---|---|
| M6. Rationing (50% of "normal" use) | SFO<br>SFI<br>MF<br>COM<br>IND<br>PUB | <br>R = 0.115 + 0.732 (Reduction target)<br>R = 0.481<br>C = 1.00 | |
| M7. Leak detection and repair | UF | 1.33(UF/TUSE)<br>R = 0.129 | 0.33 0.75 1.00 |
| M8. Pressure reduction | SFO<br>SFI<br>MF<br>COM<br>IND<br>PUB | <br>R = 0.138 | <br>C = 1.00 for all sectors |

[a]Source: Weston, Inc. 1983

in water use that can be attributed to its implementation. The total effectiveness of measure j is calculated using the formula:

$$E_{jt} = \sum_{k=1}^{s} E_{jkt} \tag{1}$$

and

$$E_{jkt} = Q_{kt} * R_{jkt} * C_{jkt} \tag{2}$$

where:

$E_{jt}$ = effectiveness of demand reduction measure j during implementation period t summed over all use sectors k = 1,...,s, (million gallons);

$E_{jkt}$ = effectiveness of demand reduction measure j for use sector k, during implementation period 5, (mg);

$Q_{kt}$ = predicted unrestricted use in sector k during implementation period t, (mb);

$R_{jkt}$ = fraction reduction in use in sector k, during implementation period t, expected as a result of implementing measure j; and

$C_{jkt}$ = coverage of measure j in use sector k, during implementation period t.

Both $R_{jkt}$ and $C_{jkt}$ are fractions, defined on the interval [0,1]. Use sectors are defined as needed for the evaluation of economic losses resulting from reductions in water delivery and the different fraction reductions expected for various use categories. For most practical purposes, the following use categories should be included: (1) residential indoor use, (2) residential outdoor use; (3) industrial by locally owned firms; (4) industrial by externally owned firms; (5) commercial/institutional; and (6) public/unaccounted for.

In the course of formulating water conservation programs, effectiveness should be estimated for each measure. Next, all measures comprising a program must be investigated for possible interactions in order to make necessary adjustments in the total effectiveness of the program. If a program represents a combination of interactive measures, the effectiveness of the program i can be calculated as:

$$E_i = I_{1/2,3}E_1 + I_{2/1,3}E_2 + I_{3/1,2}E_3 \tag{3}$$

where:

$E_i$ = effectiveness of water conservation program i, i.e. total volume of water saved by implementing the program i, during drought planning period, million gallons;

$E_1$ = effectiveness of measure no. 1, $(E_{jt})$;

$I_{1/2,3}$ = interaction factor or the fraction of the full effectiveness of measure no. 1 given that measures no. 2 and 3 are present in the same conservation program i.

Table 16 also contains the information pertinent to the determination of effectiveness of the selected demand reduction measures.

Given the information from Table 16 it is possible to calculate the effectiveness of each individual measure in terms of million of gallons of water saved. However, in order to calculate the effectiveness of a combination of measures it is necessary to identify possible interaction between measures. Table 17 gives a matrix of interaction factors for the measures which are included in Table 16. These factors are reported in the IWR report prepared by Weston, Inc. (1983).

Based on the information from Tables 16 and 17, and using the disaggregated water use data developed in Chapter II, the effectiveness of individual measures and "packages" of measures are calculated in Tables 18, and 19. Measure M4 - Rate Surcharge is not treated in Tables 18 and 19 because it requires the knowledge of water demand function for the service area. The development of such a model required an involved data gathering on water use in the area, and it is described in greater detail in the following section.

## Development of Water Demand Model

Data base. In order to develop a residential water demand model, a random sample of 180 residential customers was drawn from the telephone book and computer listings of the utility accounts. The utility customers were divided into 3 rate groups, Rate 10, Rate 11, and Rate 12, depending on geographical location. Rate 10 customers pay the lowest price for water and are located within the city limits. Table 20 shows the number of accounts and sample size within each rate category. Although the initial sample contains a more balanced representation of customers from each rate category, 75 customers had to be dropped due to either lack of a billing record of sufficient length or the refusal to respond to a telephone survey.

For each of the 105 customers, information on water use and total bills for 56 consecutive monthly billing periods, from October 1978 to May 1983, was compiled from utility records. In addition a number of explanatory variables was obtained from other sources including personal telephone interviews conducted according to the interview schedule presented in Figure 2. The complete list of variables and sources of information are presented in Table 21. The final data base comprised 5880 computer records with 22 variables on each record including customer and billing period identification numbers.

TABLE 17

INTERACTION FACTORS BETWEEN DEMAND REDUCTION MEASURES

| Implemented Measure | Measure Added | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | M1 | M2 | M3 | M4 | M5 | M6 | M7 | M8 |
| M1 | -- | 0.917 | 0.917 | 1 | 1 | 0.180 | 1 | 1 |
| M2 | 0.789 | -- | 1 | 1.213 | 1 | 1.213 | 1 | 1 |
| M3 | 0.789 | 1 | -- | 1.213 | 1 | 1.213 | 1 | 1 |
| M4 | 1 | 1.255 | 1.255 | -- | 1 | 1 | 1 | 1 |
| M5 | 1 | 1 | 1 | 1 | -- | 0.55 | 1 | 1 |
| M6 | 0.470 | 1.255 | 1.255 | 1 | 0.470 | -- | 1 | 1 |
| M7 | 1 | 1 | 1 | 1 | 1 | 1 | -- | 1 |
| M8 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | -- |

Source: Weston, Inc., 1983

TABLE 18

EFFECTIVENESS OF DEMAND REDUCTION MEASURES

| Measure | Reduction in Sectoral Water Use | | | | | | | | Total Municipal | |
|---|---|---|---|---|---|---|---|---|---|---|
| | SFO | SFI | MF | COM | IND | PUB | LOSS | POWER | SUMMER | WINTER |
| Unrestricted Use | 0.814 | 5.970 | 3.621 | 4.413 | 1.739 | 0.663 | 1.899 | 0.867 | 19.986 | 19.172 |
| M1 (modest) | 0.018 | 0.266 | 0.161 | 0.098 | 0.039 | 0.029 | 0 | 0 | 0.611 | 0.593 |
| M1 (moderate) | 0.036 | 0.398 | 0.242 | 0.196 | 0.077 | 0.044 | 0 | 0 | 0.993 | 0.957 |
| M1 (maximum) | 0.065 | 0.478 | 0.290 | 0.295 | 0.116 | 0.059 | 0 | 0 | 1.303 | 1.238 |
| M2 (modest) | 0 | 0.171 | 0.104 | 0 | 0 | 0.009 | 0 | 0 | 0.284 | 0.284 |
| M2 (moderate) | 0 | 0.341 | 0.207 | 0 | 0 | 0.019 | 0 | 0 | 0.567 | 0.567 |
| M2 (maximum) | 0 | 0.598 | 0.362 | 0 | 0 | 0.031 | 0 | 0 | 0.911 | 0.911 |
| M3 (modest) | 0 | 0.179 | 0.109 | 0.132 | 0 | 0.020 | 0 | 0 | 0.440 | 0.440 |
| M3 (moderate) | 0 | 0.358 | 0.218 | 0.264 | 0 | 0.040 | 0 | 0 | 0.880 | 0.880 |
| M3 (maximum) | 0 | 0.645 | 0.391 | 0.477 | 0 | 0.072 | 0 | 0 | 1.585 | 1.585 |
| M4 (See the next section) | | | | | | | | | | |
| M5 (modest) | 0.096 | 0 | 0 | 0.470 | 0.138 | 0.141 | 0 | 0 | 0.845 | 0.749 |
| M5 (moderate) | 0.145 | 0 | 0 | 0.705 | 0.207 | 0.141 | 0 | 0 | 1.198 | 1.053 |
| M5 (maximum) | 0.193 | 0 | 0 | 0.940 | 0.276 | 0.141 | 0 | 0 | 1.550 | 1.357 |
| M6 | 0.391 | 2.872 | 1.742 | 2.123 | 0.836 | 0.319 | 0 | 0 | 8.283 | 7.892 |

TABLE 18 (Continued)

EFFECTIVENESS OF DEMAND REDUCTION MEASURES

| Measure | Reduction in Sectoral Water Use | | | | | | | | Total Municipal | |
|---|---|---|---|---|---|---|---|---|---|---|
| | SFO | SFI | MF | COM | IND | PUB | LOSS | POWER | SUMMER | WINTER |
| Unrestricted Use | 0.814 | 5.970 | 3.621 | 4.413 | 1.739 | 0.663 | 1.899 | 0.867 | 19.986 | 19.L72 |
| M7 (modest) | 0 | 0 | 0 | 0 | 0 | 0 | 0.081 | 0 | 0.081 | 0.081 |
| M7 (moderate) | 0 | 0 | 0 | 0 | 0 | 0 | 0.184 | 0 | 0.184 | 0.184 |
| M7 (maximum) | 0 | 0 | 0 | 0 | 0 | 0 | 0.245 | 0 | 0.245 | 0.245 |
| M8 0.112 | 0.824 | 0.500 | 0.609 | 0.240 | 0.091 | 0.262 | 0 | 2.638 | 2.526 | |

Legend:
SFO = single-family outside use
SFI = single-family inside use
MF = multi-family
COM = commercial
IND = industrial
PUB = public
LOSS = distribution system losses
POWER = power station use

TABLE 19

EFFECTIVENESS OF DEMAND REDUCTION PROGRAMS

| Program | Reduction in Sectoral Water Use | | | | | | | | Total Municipal | |
|---|---|---|---|---|---|---|---|---|---|---|
| | SFO | SFI | MF | COM | IND | PUB | LOSS | POWER | SUMMER | WINTER |
| X1 to X8 | (See effectiveness for individual measures M1 to M8 | | | | | | | | -- | -- |
| X9 = M1(modest), M2(modest), M3(modest) | 0.018 | 0.587 | 0.365 | 0.219 | 0.039 | 0.056 | 0 | 0 | 1.284 | 1.266 |
| X10 = X9, M7(moderate), M8 | 0.130 | 1.411 | 0.865 | 0.828 | 0.279 | 0.147 | 0.446 | 0 | 3.836 | 3.706 |
| X11 = M1(moderate), M2(moderate), M3(moderate), M7(max.), M8 | 0.148 | 1.893 | 1.350 | 1.047 | 0.317 | 0.189 | 0.507 | 0 | 5.451 | 5.303 |
| X12 = M1(max), M2(max), M3(max), M7(max), M8 | 0.177 | 2.442 | 1.480 | 1.341 | 0.356 | 0.244 | 0.507 | 0 | 6.547 | 6.370 |
| X13 = X12, M5(modest) | 0.273 | 2.442 | 1.480 | 1.811 | 0.494 | 0.385 | 0.507 | 0 | 7.392 | 7.119 |
| X14 = X12,M5(moderate) | 0.322 | 2.442 | 1.480 | 2.046 | 0.563 | 0.385 | 0.507 | 0 | 7.745 | 7.423 |
| X15 = X12,M5 (max) | 0.370 | 2.442 | 1.480 | 2.281 | 0.632 | 0.385 | 0.507 | 0 | 8.097 | 7.727 |
| X16 + M6, M1(max) | 0.529 | 3.097 | 1.878 | 2.262 | 0.890 | 0.347 | 0 | 0 | 9.003 | 8.474 |

TABLE 20

SAMPLE AND POPULATION DATA FOR RESIDENTIAL CUSTOMERS

| Rate Category | Number of Accounts | Percent of total | Sample | Percent of Total Sample | Average Price $/1000 gal | Marginal Price $/1000 gal | Average Annual Water use gal/cust./day |
|---|---|---|---|---|---|---|---|
| 10 | 33,110 | 82 | 80 | 76 | 2.14 | 1.34 | 192 |
| 11 | 6,525 | 16 | 10 | 10 | 3.54 | 2.18 | 180 |
| 12 | 488 | 2 | 15 | 14 | 3.72 | 2.36 | 167 |
| All | 40,123 | 100.0 | 105 | 100.0 | -- | -- | 189[a] |

[a]Weighted average by actual number of customers.

RESIDENTIAL WATER-USE
INTERVIEW SCHEDULE

INTRODUCTION

1. Approximately how many years have you been living at this address?

   more than 5 years ( )     less than 5 years ( )

2. Do you pay for your own water bill? yes ( )     no ( )

3. How many persons live in your home? ______________________________

4. Have these same persons lived at this address during the last 5 years?

   If yes ( ) - go to 6     no ( ) - go to 5

5. Would you be able to give us the number of persons who have lived in your home during each year of that period?

   yes ( )     no ( ) How much he knows auxiliary questions

| Year | Month | No. of Residents |
|---|---|---|
| 1978 | | |
| 1979 | | |
| 1980 | | |
| 1981 | | |
| 1982 | | |

6. The last question is how many bathrooms in your home? ____________

   Do you:     If Yes     No About how often do you use it?

| Do you: | If Yes | No | About how often do you use it? |
|---|---|---|---|
| Water your lawn | | | |
| Have a swimming pool | | | |
| Have a washing machine | | | |
| Have a dishwasher | | | |

You have been very helpful. Thank you very much for your time and cooperation.

**Figure 2. Interview Schedule**

TABLE 21

LIST OF VARIABLES AND DATA SOURCES FOR RESIDENTIAL WATER DEMAND MODEL

| No. | Variable Definition | Source |
|---|---|---|
| 1. | Average daily water use in a billing period, gcud | Billing records |
| 2. | Number of days in the billing period | As above |
| 3. | Total bill | As above |
| 4. | Marginal price of water in each billing period | Rate schedules (from the utility) |
| 5. | Lot size | Tax assessor, areal photographs |
| 6. | Number of persons in a household | Telephone interview |
| 7. | Frequency of lawn watering, $month^{-1}$ | As above |
| 8. | Presence of a swimming pool | As above |
| 9. | Number of bathrooms | As above |
| 10. | Frequency of washing machine usage, $month^{-1}$ | As above |
| 11. | Frequency of dishwasher usage, $month^{-1}$ | As above |
| 12. | Assessed value of residence, $ | Tax assessor |
| 13. | Average temperature in a billing period, $^oF$ | NOAA publications |
| 14. | Average precipitation in a billing period, inches | As above |
| 15. | Consumer Price Index | Statistical abstracts |
| 16. | Construction Cost Index | As above |

Model estimation. The residential water use data were analyzed separately for summer and winter seasons, where the months from April to September were designated as the summer months. The resultant regression models and selected statistical data are presented in Table 22. Equations 1 and 2 in Table 22 were estimated using average price of water in each billing period, which was negatively correlated with water use. Marginal price exhibited weak but positive correlation with water use thus reflecting more the block rate structure than the consumers' response to price. The average price although exhibiting negative relationship with quantity is not a reliable parameter in the demand models since it may just reflect the effect of fixed charges on average cost of water to a consumer.

In order to mitigate the problem of unreliable price estimates, the relationship between marginal price and water use was found through comparison of aggregated data for winter and summer seasons across the three rate schedules. The results for five consecutive winters and four summers are plotted on Figure 3, and 4 respectively. The "least-square best fit" lines shown on these graphs show the existence of inverse relationships between marginal price and water use by residential customers. The price elasticities calculated to be at average use points -0.710 and -1.678 for winter and summer use, respectively.

## Determination of Economic Losses

The total cost of each alternative demand reduction program, which have been formulated and evaluated for their effectiveness in Tables 16 and 19, is comprised of the cost of implementation (usually borne by the water utility) and monetary losses resulting from cutbacks in water delivery (usually borne by the customers in various sectors). The purpose of this section is to develop separate shortage-loss relationships for those user categories which may be affected by demand reduction programs.

### Monetary Losses in Domestic Sector

Forced reduction in domestic water demand will result in lost consumer surplus which can be classified as a net loss to the area. Revenue loss associated with the reduced water use represents a flow of money between different parties of the area and should not be counted as net monetary loss to the area. Even when the water utility attempts to compensate lost revenue by introducing a surcharge on water use, the overall balance of local losses remains unchanged.

The evaluation of the magnitude of the lost consumer surplus in the domestic sector is carried out separately for winter and summer water demands. Equations 1(b) and 2(b) in Table 22 were used (after adjusting them to current use conditions) in order to calculate the losses of consumer surplus alternately during winter and summer. The results of this calculation are presented in Table 23 to 25. The estimates of the lost revenue are included to produce information for the utility manager who may choose to minimize only those losses which are sustained by the water utility. Table 25 gives lost consumer surplus and revenue calculated based on the assumption that the economic demand model for apartments is the same as the winter model of single-family customers.

TABLE 22

RESIDENTIAL WATER DEMAND MODELS

| Models | Average variable values |
|---|---|
| **Winter Use** | Average variable values: |
| 1. $Q_w = 200 - 35.5\,H - 46.1\,P_{aw}$<br>$(18.7)\ (17.4)\ (-13.6)^a$ | $Q_w = 176$ gpcud |
| $R_{adj} = 0.30$ SE = 95 | $Q_\beta = 200$ gpcud |
| 1(a) $P_w = 0.0217\,Q_w + 6.40$ | H = 2.70 persons/household |
| 1(b) $P^1{}_w = 0.0157\,Q_w + 4.72$ | $P_w = 2.60$ \$/1000 gal (average price) |
| | $P^1{}_w = 1.47$ \$/1000 gal (marginal price) |
| **Summer Use** | $F = 7.2\ \text{month}^{-1}$ (frequency of dishwasher use) |
| 2. $Q_\beta = 80 + 34.4H + 3.3F + 2.1T - 4.6R - 49.0P_\beta$<br>$(2.67)\ (11.1)\ (9.33)\ (5.34)\ (-2.81)(9.09)$ | $T = 67.2\ ^oF$ (average summer temperature) |
| $R^2{}_{adj} = 0.35$ SE = 119 | R = 3.85 inches (average summer rainfall) |
| 2(a) $P_\beta = -0.0204\,Q_s + 6.53$ | $P_\beta = 2.50$ \$/1000 gal (average price) |
| 2(b)[b] $P^1{}_\beta = -0.0060\,Q_s + 3.24$ | $P^1{}_\beta = 1.50$ \$/1000 gal (marginal price) |

[a] T-values
[b] The relationships estimated for marginal price (see Figures 3, and 4)

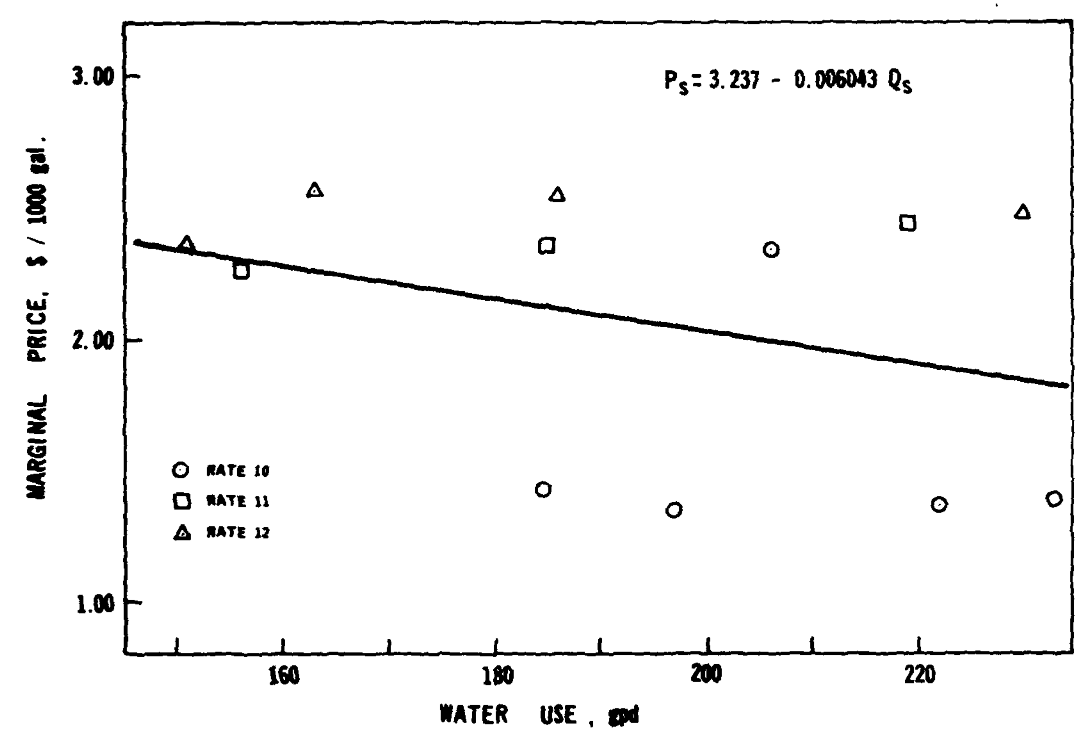


Figure 3. Price-Demand Relationship for Aggregate Data (Summer Use)

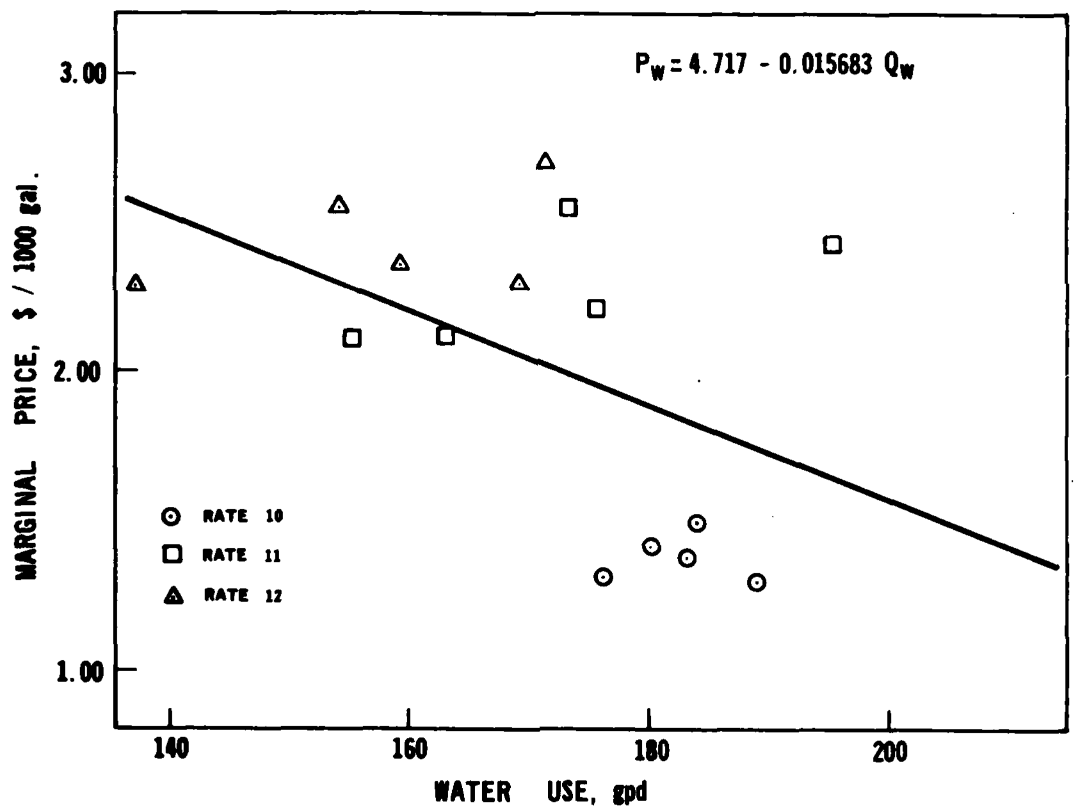


Figure 4. Price-Demand Relationship for Aggregate Data (Winter Use)

TABLE 23

ECONOMIC LOSSES RESULTING FROM CUTBACKS IN WINTER USE FOR SINGLE-FAMILY RESIDENCES OF DOMESTIC SECTOR

| Percent Cutback % (1) | Volume of Water Saved: Per Customer (gpcud) (2) | Volume of Water Saved: Total (mgd) (3) | Lost Consumer Surplus: Per Customer $/cu/mo (4) | Lost Consumer Surplus: Monthly Total $/mo (5) | Lost Revenue: Per Customer $/cu/mo (6) | Lost Revenue: Monthly Total $/mo (7) |
|---|---|---|---|---|---|---|
| 10 | 17.6 | 0.597 | 0.27 | 9,200 | 0.65 | 22,000 |
| 20 | 35.2 | 1.194 | 0.69 | 23,400 | 1.30 | 44,100 |
| 30 | 52.8 | 1.739 | 1.26 | 42,700 | 1.95 | 66,100 |
| 40 | 70.4 | 2.388 | 1.96 | 66,500 | 2.11 | 71,600 |
| 50 | 88.0 | 2.985 | 2.82 | 95,600 | 2.64 | 89,500 |
| 60 | 105.6 | 3.582 | 3.82 | 129,600 | 2.50 | 84,800 |
| 70 | 123.2 | 4.179 | 4.97 | 168,600 | 2.92 | 99,000 |
| 80 | 140.8 | 4.776 | 6.27 | 212,800 | 3.34 | 113,300 |

Col. (3) = Col.(2) X 33,920
Col. (6) = Marginal price X (Col.(2) - 1000) X 30 (Price = $1.23 for 10-30%, $1.00 for 40, 50%, and $0.79 for 60-80%)
Col. (7) = Col.(6) x 33,920
Col. (4) = Calculated from equation $P_w = 3.99 - 0.015683\ Q_w$, Col. (4) = 0.5 (Col.(2) - 1000) (Price -1.23) X 30
Col. (5) = Col.(4) X 33,920

TABLE 24

ECONOMIC LOSSES RESULTING FROM CUTBACKS IN SUMMER USE FOR SINGLE-FAMILY RESIDENCES OF DOMESTIC SECTOR

| Percent Cutback % (1) | Volume of Water Saved: Per Customer (gpcud) (2) | Volume of Water Saved: Total mgd (3) | Lost Consumer Surplus: Per Customer $/cu/mo (4) | Lost Consumer Surplus: Monthly Total $/mo (5) | Lost Revenue: Per Customer $/cu/mo (6) | Lost Revenue: Monthly Total $/mo (7) |
|---|---|---|---|---|---|---|
| 10 | 20 | 0.678 | 0.036 | 1,200 | 0.74 | 25,100 |
| 20 | 40 | 1.357 | 0.144 | 4,900 | 1.48 | 50,200 |
| 30 | 60 | 2.035 | 0.324 | 11,000 | 2.21 | 75,000 |
| 40 | 80 | 2.714 | 0.576 | 19,500 | 2.40 | 81,400 |
| 50 | 100 | 3.392 | 0.90 | 30,500 | 3.00 | 101,800 |
| 60 | 120 | 4.070 | 1.30 | 44,100 | 2.84 | 96,300 |
| 70 | 140 | 4.749 | 1.78 | 60,400 | 3.32 | 112,600 |
| 80 | 160 | 5.427 | 2.33 | 79,000 | 3.79 | 128,600 |

Col (4) = 0.5X(Col.(2)+1000)X(Price - 1.23) X 30, Equation: $P_s = 2.44 - 0.006043\ Q_s$

TABLE 25

ECONOMIC LOSSES RESULTING FROM CUTBACKS IN WATER USE FOR MULTI-FAMILY UNITS OF DOMESTIC SECTOR

| Percent Cutback % (1) | Volume of Water Saved: Per Customer (gpcud) (2) | Volume of Water Saved: Total mgd (3) | Lost Consumer Surplus: Per Customer \$/cu/mo (4) | Lost Consumer Surplus: Monthly Total \$/mo (5) | Lost Revenue: Per Customer \$/cu/mo (6) | Lost Revenue: Monthly Total \$/mo (7) |
|---|---|---|---|---|---|---|
| 10 | 29.6 | 0.362 | 0.20 | 2,400 | 0.95 | 11,600 |
| 20 | 59.2 | 0.724 | 0.82 | 10,000 | 1.90 | 23,200 |
| 30 | 88.8 | 1.086 | 1.85 | 22,600 | 2.85 | 34,900 |
| 40 | 118.0 | 1.443 | 3.27 | 40,000 | 3.79 | 46,400 |
| 50 | 148.0 | 1.810 | 5.15 | 63,000 | 4.75 | 58,100 |
| 60 | 177.6 | 2.172 | 7.43 | 90,900 | 5.70 | 69,700 |
| 70 | 207.2 | 2.535 | 10.10 | 123,500 | 6.65 | 81,300 |
| 80 | 236.8 | 2.897 | 13.18 | 161,200 | 7.60 | 93,000 |

Col. (2) = % Red. X 296 gpcud
Col. (3) = Col. (2) X 12,233
Col. (4) = 0.5 x (Col. (2) - 1000) X (Price - 1.07) X 30, Equation $P_m = 5.71 - 0.015683\, Q_m$

Industrial Losses

Industrial losses are the most difficult to estimate. In water sensitive industries, production is related to water availability and reductions in water delivery to these plants may result in production cut-backs. The information on the most likely responses of local industrial companies to cut-backs in water delivery were identified through personal interviews held with plant managers or plant engineers of 9 companies, of which 3 are locally owned and 6 are externally owned. The interview was conducted according to the interview schedule shown in Figure 5.

The industrial losses are calculated separately for the locally owned and externally owned companies. For locally owned firms, the profits after taxes and fixed costs, both losses due to cut backs in production or temporary shut down, are assumed to represent a net monetary loss to the area. The losses associated with cut-backs in water delivery to externally owned industrial firms are represented by a loss of production payroll sustained by the local employee and a loss of water company revenue. Both components constitute monetary losses to the study area. Future anticipated production cut-backs in response to reduced water supplies are shown in Table 26. Tables 27 and 28 contain calculations of the production payroll for the six externally owned companies. Losses of profits and fixed costs incurred by locally owned companies are calculated in Table 29 and 30. The calculation procedures used to obtain all estimates are those described in IWR Report 72-6, A Methodology for Assessing Economic Risk of Water Supply Shortages.

Water Utility Revenue Lost to Externally Owned Industry

The loss of water utility revenue is clearly a regional loss and it is estimated at $1.40/1000 gallons of reduction in industrial water use according to the current water rates. Since locally owned firms use a relatively small fraction of total industrial water consumption, any cut-back in industrial water deliveries may be counted as a loss to external interests.

## Economic Losses for Individual Measures

Having estimated the effectiveness of various demand reduction measures in each user sector, it is now possible to estimate the regional losses using the relationships between the reduction in water delivery and the monetary losses born by customers. The total cost of each measure will also include the cost of implementation. Brief discussion of these costs for individual measures is given below, while the estimates of total costs for individual measures are summarized in Table 31.

Measure M1 - Public Information Campaign

The implementation cost of this measure will amount to $6,000. This sum will cover the cost of four printings of water bill inserts. According to the estimates presented in Table 18 the effectiveness of this campaign should save from 0.593 to 1.303 mgd depending on its intensity and the season. Although public information will achieve the reduction in water

# INTERVIEW SCHEDULE: INDUSTRIAL FIRMS

A. General

Name of Comapny________________________________________
Address______________________________________________
Company in Business
    In this city since____________________________________
    At this plant site since______________________________
Main Product Lines______________________________________
Person Interviewed______________________________________
Position of Interviewee___________________________________
Telephone Number_______________________________________

B. COMPANY'S INTAKE OF WATER BY SOURCE

From Public Water System
From Company's Water System
    Surface
    Ground

C. PROJECTED OPERATIONS DURING POTENTIAL SUPPLY SHORTAGE

What actions would your company be likely to take in the future if your supplies of water are reduced by

10%__________________________________________________

20%__________________________________________________

30%__________________________________________________

40%__________________________________________________

50%__________________________________________________

75%__________________________________________________

100%_________________________________________________

Figure 5. Industrial Interview Schedule

TABLE 26

ANTICIPATED PRODUCTION CUT-BACKS IN RESPONSE TO REDUCED WATER SUPPLIES

| Company Number | Percent Reduction in Water Supply 10% | 20% | 30% | 40% | 50% | 75% | 100% |
|---|---|---|---|---|---|---|---|
| 1 | None | None | 10% | 20% | 30% | 100% | 100% |
| 2 | None | None | 25% | 25% | 100% | 100% | 100% |
| 3 | None | 20% | 30% | 40% | 50% | 75% | 100% |
| 4 | None | None | 100% | 100% | 100% | 100% | 100% |
| 5 | 10% | 20% | 30% | 40% | 50% | 100% | 100% |
| 6 | None | None | 40% | 40% | 40% | 75% | 100% |
| 7 | None | None | 15% | 30% | 40% | 100% | 100% |
| 8 | None | 5% | 10% | 15% | 25% | 100% | 100% |
| 9 | 10% | 20% | 30% | 40% | 50% | 75% | 100% |

TABLE 27

AVERAGE WEEKLY PRODUCTION PAYROLL IN EXTERNALLY OWNED COMPANIES

| Company Number (1) | SIC Class (2) | Average No. of Production Empl. (3) | Average Weekly Wages Per Production Worker (4) | Estimated Average Weekly Production Payroll (5) |
|---|---|---|---|---|
| 1 | 3523 | 600 | $321 | $192,600 |
| 2 | 2048 | 450 | 309 | 139,000 |
| 3 | 721[a] | 88 | 176 | 15,500 |
| 4 | 3714 | 240 | 276 | 66,200 |
| 5 | 2086 | 145 | 266 | 38,600 |
| 6 | 2992 | 28 | 240 | 6,700 |

[a]Not manufacturing company.

TABLE 28

LOSS IN WEEKLY PRODUCTION PAYROLLS CAUSED BY REDUCED WATER SUPPLIES

| Company Number | Lost Payroll at the Reduction in Water Supply: 10% | 20% | 30% | 40% | 50% | 75% | 100% |
|---|---|---|---|---|---|---|---|
| 1 | $None | $None | $19,300 | $38,500 | $ 57,800 | $192,600 | $192,600 |
| 2 | None | None | 34,800 | 34,800 | 139,000 | 139,000 | 139,000 |
| 3 | None | 3,100 | 4,600 | 6,200 | 7,700 | 11,600 | 15,500 |
| 4 | None | None | 66,200 | 66,200 | 66,200 | 66,200 | 66,200 |
| 5 | 3,900 | 7,700 | 11,600 | 15,400 | 19,300 | 38,600 | 38,600 |
| 6 | None | None | 2,700 | 2,700 | 2,700 | 6,700 | 6,700 |
| Totals | $3,900 | $10,800 | $139,200 | $163,800 | $292,800 | $454,800 | $458,700 |

TABLE 29

ESTIMATED PROFITS AND FIXED COSTS FOR LOCALLY OWNED COMPANIES (1977 DATA)

| Company Number | 7 | 8 | 9 |
|---|---|---|---|
| SIC Classification | 2086 | 2033 | 2097 |
| No. of Production Workers | 22 | 30 | 20 |
| Average Annual Wages Per Production Worker | $ 13,800 | 8,700 | 11,100 |
| Annual Production Payroll | $304,000 | 262,000 | 223,000 |
| Production Payroll to Value of Shipments | 5.27% | 5.27 | 5.27 |
| Estimated Value of Shipments | $5,775,000 | 4,974,000 | 4,224,000 |
| Profits After Taxes per Dollar of Sales | 5% | 5 | 5 |
| Estimated Profits After Taxes | 212,000 | 249,000 | 211,000 |
| Value Added (less Production Payroll) to Value of Shipments | 25.7% | 25.7 | 25.7 |
| Estimated Fixed Costs | $1,487,000 | 1,281,000 | 1,088,000 |
| Profits Plus Fixed Costs | $1,699,000 | 1,529,000 | 1,299,000 |
| Profits Plus Fixed Costs Per Production Worker Per Week | $1,480 | 980 | 1,250 |

TABLE 30

LOST PROFITS AND FIXED COSTS CAUSED BY REDUCED WATER SUPPLIES

| Company Number | Lost Profits and Fixed Costs at the Reduction in Water Supply: 10% | 20% | 30% | 40% | 50% | 75% | 100% |
|---|---|---|---|---|---|---|---|
| 7 | $None | $None | $4,400 | $10,400 | $13,400 | $32,700 | $32,700 |
| 8 | None | None | 2,900 | 3,900 | 6,900 | 29,400 | 29,400 |
| 9 | None | 5,000 | 7,500 | 10,000 | 12,500 | 18,700 | 25,000 |
| Totals | -- | $5,000 | $14,800 | $24,300 | $32,800 | $80,800 | $87,000 |

TABLE 31

SECTORAL LOSSES RESULTING FROM INDIVIDUAL DEMAND REDUCTION MEASURES ($/month)

| Measure | Sector Use | Summer Modest | Summer Moderate | Summer Maximum | Winter Modest | Winter Moderate | Winter Maximum |
|---|---|---|---|---|---|---|---|
| M1 | SF | $4,300 | $6,600 | $8,300 | $4,100 | $6,100 | $7,300 |
| | MF | 1,100 | 1,600 | 2,000 | 2,100 | 1,600 | 2,000 |
| Total | | 5,400 | 8,200 | 10,300 | 5,200 | 7,700 | 9,300 |
| M2, M3 | Only negligible losses in the affected sectors | | | | | | |
| M4 | DOM | $147,300 | $230,200 | -- | $135,400 | $210,900 | -- |
| | COM | 62,200 | 97,100 | -- | 62,200 | 97,100 | -- |
| | IND | 24,000 | 37,500 | -- | 24,000 | 37,500 | -- |
| Total | | 233,500 | 364,800 | | 221,600 | 345,500 | |
| M5 | Only negligible losses in domestic and industrial sectors | | | | | | |
| M6 | SF | $ 30,500 | | | | $ 95,600 | |
| | MF | 63,000 | | | | 63,000 | |
| | $IND_e$ | 1,268,700 | | | | 1,268,700 | |
| | $IND_1$ | 141,900 | | | | 141,800 | |
| | UTIL | 35,100 | | | | 35,100 | |
| | | 1,539,100 | | | | 1,604,200 | |
| M7, M8 | Small costs borne by water utility | | | | | | |

SF = Single-family, MF = multifamily, $IND_e$ = external industrial, $IND_1$ = local industrial
UTIL = water utility, DOM = domestic total

use through appeals for voluntary conservation, the consumer cost of such reduction will be the sacrificed consumer surplus in domestic sector and the increased operation costs incurred by industrial customers. Since the reductions in industrial sector will be less than 7 percent, even at the maximum intensity campaign, it is unlikely that any layoffs of production workers will take place and the industrial cost may be considered negligible.

Measures M2 and M3 - Distribution of Low Flow Shower Heads and Toilet Inserts

These two measures will not impose any significant hardships on consumers under the assumption that these water saving devices will not produce noticeable impairment in the performance of the affected fixtures. The only cost of these measures will be that born by the water utility. It is estimated that the purchase of this devices will cost $60,000 dollars. If the utility personnel install these fixtures, then the estimated cost of installation would be:

30,000 sets * 1.0 hr labor = 30,000 hrs

30,000 hrs * $8.50/hr = $255,000

Measure M4 - Water Rate Surcharge

The effectiveness of this measure has not been calculated in the previous sections since it required the knowledge of econometric water demand models. The consumer response to a rate surcharge calculated as a percentage of the total bill can be best approximated by an econometric model using the average price as an explanatory variable. Equations 1(a) and 2(a) from Table 22 show the estimated relationship between average price and water use in the domestic sector. Accordingly, the decrease in winter use caused by the 30 percent surcharge on the total water bill can be calculated from the relationship:

$$\frac{Q_2}{Q_1} = \left(\frac{P_2}{P_1}\right)^e$$

where

$P_1$ = (total bill)/$Q_1$

$P_2$ = ((Total bill) x 1.3)/$Q_1$

$P_2/P_1 = 1.3$

$e = ((6.40/-0.0217)-176)/176 = -0.676$

$Q_2 = Q_1\ (1.3)^{-0.676} = 176\ (1.3)^{-0.676} = 147$ gpcd

Effectiveness = (176 - 147) * (33,920 + 12,233) = 1.338 mgd

For summer use the respective values are: $Q_1$ = 200 gpcd;

$e = ((6.53/-0.0204)-200)/200 = -0.600$; and

$$Q_2 = 200\ (1.3)^{-0.600} = 171 \text{ gpd}$$

$$\begin{aligned} \text{Effectiveness} &= (200-171) * (33{,}920) = 0.984 \text{ mgd} \\ &\phantom{=}\ (176-147) * (12{,}233) = \underline{0.355} \\ &\qquad\qquad \text{Total} \qquad\qquad 1.339 \text{ mgd} \end{aligned}$$

At a 50 percent increase of the total bill, the reductions calculated according to the above procedure will be 1.938 mgd in winter and 1.972 mgd in summer.

The consumer cost of the rate surcharge is clearly classified as a regional monetary loss caused by a drought. In the domestic sector, the average total bill is \$11.76 and \$12.26 in winter and summer, respectively. Assuming that due to the 30 percent rate surcharge, average consumption drops from 176 gpcd to 147 gpcd, in winter, and from 200 gpcd to 171 gpcd, in summer, the reduced total bills before surcharge would be \$9.78 and \$10.95, respectively. The additional revenue raised by imposing the surcharge in the domestic sector during winter would be,

$$\$9.78 * 0.30 * (33{,}920 + 12{,}233) = \$135{,}000/\text{month}$$

and during summer

$$\$10.95 * 0.30 * (33{,}920) + \$9.78 * 0.30 * (12{,}233) = \$147{,}000/\text{month}.$$

The respective estimates for a 50 percent surcharge would be \$211,000 in winter, and \$230,000 in summer.

The effectiveness and economic losses in non-residential sectors cannot be estimated using the above method due to the lack of price-quantity relationships for these sectors. A rough estimate can be obtained by allocating the revenue increase and the reduction in water use according to the total sectoral water use in comparison to residential use. If the average annual reduction in domestic water use resulting from a 30 percent surcharge is 1.338 mgd, then the expected savings in commercial and public sectors are

Commercial - 1.338 * (4,413,000/9,998,000) = 0.591 mgd

Industrial - 1.338 * (1,739,000/9,998,000) = 0.233 mgd

Similarly, at a 50 percent surcharge

Commercial - 1.955 * 0.44 = 0.863 mgd

Industrial - 1.955 * 0.17 = 0.340 mgd

The revenue gain due to the surcharge can be allocated in the same manner.

Commercial - \$141,000 * 0.44 = \$62,000/month @ 30%
\$221,000 * 0.44 = \$97,000/month @ 50%

Industrial - \$141,000 * 0.17 = \$24,000/month @ 30%
\$221,000 * 0.17 = \$37,000/month @ 50%

Further calculations would be needed in order to estimate the effectiveness and the consumer cost of the rate surcharge introduced at lower levels of water use, i.e. when other measures are already in effect.

Measure M5 - Restrictions on Nonessential Uses

For this measure the total cost will be comprised only of the consumer losses in the various sectors. Since the lost receipts of the commercial sector are assumed to represent money transfers among various sectors within the area, the cost of this measure includes the consumer surplus and industrial losses. However, because the reduction in water use in both sectors will be less than 10 percent, and only non-essential uses will be restricted, the assumption of negligible losses is justified.

Measure M6 - Rationing

Water rationing aimed at the reduction of 50 percent of normal water use will have a substantial economic impact on domestic and industrial sectors as well as on the water utility. The domestic sector losses will be represented by the lost consumer surplus calculated in Tables 23 to 25. Industrial losses will include the payroll losses shown in Table 28 and the lost profits and fixed costs which are summarized in Table 30.

Measures M7 and M8 - Leak Detection and Repair and Pressure Reduction

The implementation costs of these two measures cannot be estimated with sufficient accuracy. However, due to the fact that the leak detection and repair is a part of a long-run system maintenance program the extra costs to the utility will not be significant. On the customer side, these two measures will not cause any hardships unless there is insufficient pressure to provide water for all customers.

# IV. EVALUATION OF EMERGENCY WATER SUPPLIES

## Existing and Potential Sources

A detailed evaluation of emergency water supplies for the Springfield water supply system has been conducted by Crawford, Murphy and Tilly, Inc. (CMT, 1982). The CMT staff has investigated a number of potential emergency supplies with an aim to provide supplemental water sources in the event of a severe drought. This analysis included all the necessary considerations, namely:

(1) availability and quality of water in potential emergency sources during persisting dry weather conditions;

(2) adequacy of existing treatment facilities to produce finished water of acceptable quality when emergency supplies make up some fraction of new water supply;

(3) lead time required to construct necessary water transmission and pre-treatment facilities (if required);

(4) construction costs required to bring emergency sources on line; and

(5) potential obstacles to implementation such as institutional barriers, right-of-way considerations, and operational permits.

The remainder of this section gives a summary of the major findings of the CMT report.

A limited additional supply of water can be obtained without significant capital outlays from existing pumping facilities. One such facility, rated at 9 mgd is available to pump water from lagoons below the lake dam (Spaulding Dam). These lagoons receive backwash water from the filter plant and wastewater (ash sluicing) from power plant operations. The CMT staff has estimated the quantity of water available from this source at 2.71 mgd in 1975. Another source of the supplemental supply can be obtained from the South Fork River which flows near the Springfield Lake. A channel dam and pumping facilities rated at 60 mgd were constructed during the 1952-1955 drought in order to supplement the depleted storage of the lake. The available supply from this source was estimated by the CMT staff at 13.0 mgd during a 40-year drought of 18-month duration (with provision for 0.7 mgd leakage through the dam). During a 100-year drought the low flow is expected to be 8.3 mgd.

The search for additional sources of supply during drought emergencies carried out by the CMT staff has led to the selection of an auxiliary supply system which would be constructed only after a severe drought and an imminent shortage of water from Lake Springfield have been recognized. This alternative provides for the construction of a temporary channel dam in Sangamon River, which would back up the Sangamon flow to the existing pumping facilities at South Fork. This system would provide ample supply of water, well above 20 mgd, even when maintaining minimum streamflow in

the Sangamon River. The construction of this system would take about 60 days and it would cost $1,043,000 (CMT, 1982).

Costs of Emergency Supplies

In order to evaluate the emergency water supplies, it is necessary to determine both the investment and the operation and maintenance costs for each supply system. Since these costs were not specified in the CMT reports, it was assumed that total operation and maintenance cost is $6/mg for the pumping facility rated at 9 mgd and $4/mg for the 60 mgd facility based on the literature data (Steel and McGhee, 1979). The summary of the available supply and costs of emergency sources is presented in Table 32.

TABLE 32

AVAILABLE YIELD AND COSTS OF EMERGENCY
WATER SUPPLIES

| Source | Yield, mgd | | Pumping | Cost, $ | |
|---|---|---|---|---|---|
| | 100-year | 40-year | Capacity, mgd | Initial | O&M |
| 1. Backwash and Ash Sluicing Lagoons | 2.71 | 2.71 | 9 | -- | $6/1 mg |
| 2. Existing South Fork Facility | 8.3 | 13.0 | 60 | -- | $4/1 mg |
| 3. Proposed Sangamon River Supply | >20.0 | >20.0 | 60/80 | 1,043,000 | $4/1 mg |

# V. DETERMINATION OF OPTIMAL SHORTAGE MITIGATION PLANS

## Feasible Drought Emergency Measures

The information on demand and loss reduction programs and emergency water supplies developed in Chapters III and IV is integrated here to formulate a final list of drought emergency measures. Since there are a very large number of combinations of various measures which may be used to assemble the "packages" of measures, their full evaluation requires the use of a computer. However, in order to illustrate the procedure of selecting the best sets of measures, only a limited number of combinations is used.

Table 33 contains the summary of information for the 16 demand and loss reduction programs shown in Tables 18 and 19. In order to compare the effectiveness of individual programs in terms of the cost of water saved, a total unit cost of water for each measure is also included. Water saved or supplied from emergency sources is calculated from the data included in Tables 18 and 19 which were adjusted to reflect the duration of a measure.

## Optimal Shortage Mitigation Plans

The results presented in Table 33 provide valuable information for selecting the "best packages" of drought emergency measures. The estimated unit costs per 1 mg of water saved (or supplied) shows that such measures as distribution of water saving devices (M2, M3), restrictions on non-essential uses (M5), leak detection and repair (M7) and pressure reduction (M8) can provide considerable water savings at relatively low cost. On the other hand, water rate surcharge and rationing are extremely "expensive," since they impose substantial economic losses on customers. Combination of the less damaging measures can produce comparable savings to those obtained through rationing, at much lower cost.

Emergency water supplies are the cheapest source of water, however, $Y_1$ and $Y_2$ are already in place and no initial investment cost is needed. If construction of transmission facilities are needed then the costs of these supplies would increase considerably. Emergency supply system $Y_3$ represents more typical conditions than the other two systems. It requires about $1 million for construction of a temporary dam and the average unit cost of water obtained from this source will decrease as the amount of water supplied increases.

Having determined the effectiveness and total regional costs of the drought emergency measures, it is possible to select those combinations of measures which provide a required quantity of water (to make up for expected deficit) at minimum cost. The results of the manual selection of the "best" combination of measures to alleviate previously determined levels of deficits from Table 14 are presented in Table 34.

The total costs of the drought management programs may be reduced by inclusion of additional measures and using a computer program to select the least cost programs. Manual computation is only possible when some simplifying assumptions are made. Nevertheless, the results presented in Table 34 clearly show how the cost of drought mitigation increases in the future especially for low probability events.

TABLE 33

EFFECTIVENESS AND COSTS OF DROUGHT EMERGENCY MEASURES

| Measure: Demand or Loss Reduction Program (X) or Emergency Supply (X) | Duration (months) | Water Saved or Supplied During the 18-Month Period of Emergency (mgd) | Total Regional Cost Initial ($) | Total Regional Cost Monthly ($/month) | Unit Cost ($/mg) |
|---|---|---|---|---|---|
| X 1 (M1") | 18 | 0.981 | $ 6,000 | $ 8,100 | $ 286 |
| X 2 (M2") | 18 | 0.567 | 30,000 | -- | 96 |
| X 3 (M3") | 18 | 0.880 | 30,000 | -- | 62 |
| X 4 (30% Surcharge) | 6 | 0.721 | -- | 233,600 | 3,600 |
| X 5 (M5") | 6 | 0.399 | -- | -- | 10 |
| X 6 (M6) | 3 | 1.380 | -- | 1,539,100 | 6,200 |
| X 7 (M7") | 6 | 0.061 | -- | -- | 10 |
| X 8 (M8) | 3 | 0.440 | -- | -- | 10 |
| X 9 (M1'+M2'xM3') | 18 | 1.284 | 66,000 | 5,300 | 231 |
| X 10 (X9+M7"+M8) | 18 | 3.793 | 66,000 | 8,100 | 103 |
| X 11 (M1"+M2"+M3"+M7"'+M8) | 18 | 5.402 | 66,000 | 8,100 | 77 |
| X 12 (M1"'+M2"'+M3"'+M7"'+M8) | 18 | 6.488 | 66,000 | 9,900 | 70 |
| X 13 (X12+M5') | 6 | 2.445 | 66,000 | 9,900 | 98 |
| X 14 (X12+M5") | 6 | 2.582 | 66,000 | 9,900 | 90 |

TABLE 33 (Continued)

EFFECTIVENESS AND COSTS OF DROUGHT EMERGENCY MEASURES

| Measure: Demand or Loss Reduction Program (X) or Emergency Supply (X) | Duration (months) | Water Saved or Supplied During the 18-Month Period of Emergency (mgd) | Total Regional Cost Initial ($) | Total Regional Cost Monthly ($/month) | Unit Cost ($/mg) |
|---|---|---|---|---|---|
| X 15 (X12+M5"') | 6 | 2.699 | 66,000 | 9,900 | 85 |
| X 16 (M6+M1"') | 3 | 1.500 | 6,000 | 1,539,100 | 5,700 |
| $Y_1$ | 18 | 2.710 | -- | -- | 6 |
| $Y_2$ (40-year drought) | 18 | 13.000 | -- | -- | 4 |
| $Y_3$ (100-year drought) | 18 | 8.300 | -- | -- | 4 |
| $Y_3$ | 1 | 3.333 | 1,043,000 | -- | 583 |
| | 3 | 10.000 | 1,043,000 | -- | 197 |
| | 6 | 20.000 | 1,043,000 | -- | 100 |
| | 7.5 | 25.000 | 1,043,000 | -- | 80 |

', ", "', designate modest, moderate, and maximum intensity of a given measure.

TABLE 34

DROUGHT MANAGEMENT PROGRAMS FOR FUTURE DEFICITS IN WATER SUPPLY

| Year | Probability | Potential Deficit During 18-Month Drought, (mgd) | Drought Management Program (Water saved or supplied by Drought Emergency Measures) (mgd) | Total Cost ($) |
|---|---|---|---|---|
| 1980 | 0.10 | 0 | -- | -- |
| | 0.04 | 0 | -- | -- |
| | 0.025 | 3.3 | $Y_2 = 3.3$ | $ 7,200 |
| | 0.01 | 8.6 | $Y_2 = 3.3$ | 18,800 |
| 1990 | 0.10 | 0 | -- | -- |
| | 0.04 | 0.5 | $Y_2 = 0.5$ | $ 1,100 |
| | 0.025 | 6.5 | $Y_2 = 6.5$ | 14,200 |
| | 0.01 | 12.1 | $Y_2 = 8.3, Y_1 = 2.71$, X9 = 1.284 | 189,600 |
| 2000 | 0.10 | 0 | -- | -- |
| | 0.04 | 7.4 | $Y_2 = 7.4$ | $ 16,200 |
| | 0.025 | 11.4 | $Y_2 = 11.4$ | 25,000 |
| | 0.01 | 17.4 | $Y_2 = 8.3$, $Y_1 = 2.71$, X12 = 6.488 | 276,000 |
| 2010 | 0.10 | 0 | -- | -- |
| | 0.04 | 10.7 | $Y_2 = 10.7$ | $ 23,400 |
| | 0.025 | 14.6 | $Y_2 = 13.0$, $Y_1 = 1.6$ | 33,800 |
| | 0.01 | 20.4 | $Y_3 = 20.4$ | 1,117,900 |
| 2020 | 0.10 | 1.5 | $Y_2 = 1.5$ | $ 3,300 |
| | 0.04 | 16.2 | $Y_2 = 16.2$ | 35,500 |
| | 0.025 | 20.0 | $Y_3 = 20$ | 1,096,000 |
| | 0.01 | 25.6 | $Y_3 = 25.6$ | 1,096,000 |

## Cumulative Cost of Shortage Mitigation

The results presented in Table 34 may be transformed in order to calculate the expected value of the total cost of shortage mitigation. The expected cost of drought in 1980 was:

$$0.025 * 7,234 + 0.01 * 18,851 = \$369$$

In the year 2020 this cost (present worth) would be:

| | | | | |
|---|---|---|---|---|
| 1.10 | * | $3,288 | = | $300 |
| 0.04 | * | 35,510 | = | 1,400 |
| 0.025 | * | 1,096,000 | = | 27,000 |
| 0.01 | * | 1,096,000 | = | 11,000 |
| | | Total | | 39,700 |

Based only on those two years, the average expected cost of mitigating a drought event is about $20,000, and the cumulative cost during the 40-year planning period can be calculated as:

$$\frac{40 \times 12 \text{ mo}}{18 \text{ mo.}} * \$20,000 = \$533,000$$

Theoretically, if the proposed new lake is constructed in Springfield and it eliminates the possibility of having any measurable water deficit during this period, then the cost of that lake (about $38 mln) would eliminate the risk of incurring about $0.5 mln of drought losses.

However, the above comparison should be interpreted with extreme caution since it involved the comparison of relatively certain costs of system expansion with uncertain costs of droughts.

# VI. CONCLUSIONS

The application of the DROPS procedure to evaluate drought emergency alternatives for the water supply system in Springfield, Illinois, gave rise to several important considerations. These are presented below.

A comprehensive evaluation of drought management alternatives can be successfully performed following the specific steps of the DROPS procedure, however, the needs for data from highly diversified sources and overall data deficiencies may result in suboptimal selections of drought management measures. Also, manipulation of large information bases and involved mathematical calculations make application of this procedure to a specific water supply system very costly. The whole analytical effort requires 9 to 12 man-months.

Future research effort in this area should be directed toward the development of a universal information base and computerization of several mathematical algorithms used in the DROPS model. The analytical elements of the procedure that can be performed using generalized parameters include: (1) loss functions; (2) price-demand relationships; (3) cost functions for typical emergency supply systems; (4) effectiveness and cost relationships of specific demand and loss reduction programs, and (5) short-term water supply and demand forecasting models. The existing computerized system such as IWR MAIN are indispensable in the practical application of the DROPS procedure. Additional computational tools similar to IWR MAIN should be developed. Two modules which could be easily developed are: (1) calculation of effectiveness of typical demand and loss reduction measures; and (2) mathematical optimization procedure for solving the mixed integer problem formulated in Volume I of this report.

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